A Study of Mottled Images in an Intermediate Transfer Belt System

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Abstract

Canon has developed a two-layered intermediate transfer belt (ITB) that reduces the density unevenness that causes mottled images, and introduced it on the LBP7200C color laser printer. One of the technical advantages of this ITB system is that it can support a variety of media including other than plain media. However, one of the major technical challenges in an ITB is mottled images, which are considered to be caused by unevenness in transfer efficiency in the secondary transfer process. This report explains the development of a tool for measuring toner adhesion force to an ITB after the primary transfer process, and the results of such measurements. Based on experiments and numerical simulation of the secondary transfer process, the reduction of mottled images in a two-layered ITB by low toner adhesion force is also discussed.

Introduction

Presently, many color laser printers employ intermediate transfer methods, but one of the principal technical problems of these methods is mottled images. In order to improve mottled images, Canon developed a two-layered intermediate transfer belt (ITB) and installed it in the LBP7200C, which was launched in March 2009. Mottled images are considered to be caused by unevenness of the transfer efficiency owing to the surface shape irregularity of the transfer medium [1]. In this study, the toner adhesion force to the two-layered ITB and to a single-layered polyimide ITB (PI ITB) was measured by a device that was newly developed to measure the adhesion force of the toner transferred onto the ITB after the primary transfer process. The factors that determine the extent of mottled images were also studied based on the simulation results of the secondary transfer process.

LBP7200C

Product outline

The LBP7200C is a compact A4 color laser printer that offers high speed, high image quality, a wide variety of paper handling, space-saving design, and environmental friendliness. The key technical features of the printer engine are four-series tandem intermediate transfer, single component contact development, and on-demand fusing. The outside view and basic specifications of the LBP7200C are shown in Fig. 1 and Table 1, respectively.

Figure 1. *LBP7200C*

Table 1 Specifications of LBP7200C

Type	Desktop color laser printer
Printing method	Electrophoto method (rapid fusing system)
First-print time	15 s or less
Print speed (BW/color)	Up to 20/20 ppm (A4)
Warm-up time	19 s or less from power on
Recovery time	18 s or less from sleep state
Typical electricity consumption	1.44 kWh/week
Paper weight	60 to 220 g/cm^2
Dimensions (W x D x H)	409×490×331 mm

Two-layered ITB

The two-layered ITB is composed of a surface layer which has a thickness of 3 μm and is made of acrylic resin added with a conductive agent, and a base layer which has a thickness of 70 μm and is made of polyester resin added with a conductive agent. Figure 2 shows photos of fixed red solid images formed by using the (a) two-layered ITB and (b) PI ITB, which were primary-transferred onto an ITB at magenta and yellow stations in this order, secondary-transferred onto paper, and then fixed. Mottled images are seen at the points where the upper magenta layer is lost and the lower yellow layer appears. The mottling of the two-layered ITB is less than that of the PI ITB.

Mottled images

A model is presented in order to study mottled images by examining unevenness of the transfer efficiency due to the surface shape irregularity of the transfer medium, which is considered to cause the mottled images.

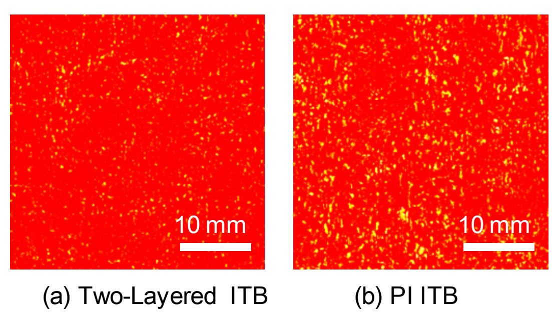

Figure 2. *Mottled images*

Dependency of secondary transfer efficiency on surface profile of transfer medium

The surface profile of the transfer medium was measured by focusing on the depth. A sculpted sheet (a resin sheet on the surface of which recesses were formed) was used instead of a transfer medium to examine the dependency of secondary transfer efficiency on the depth of recesses on the transfer medium surface. A secondary transfer bias of 3.0 kV was used. The sculpted sheet was made by laser-sculpting the recesses in an area of 1 mm^2 on the surface of a 125 µm-thick polyethylene terephthalate (PET) sheet. Figure 3 is a photo of a red solid image transferred from the area of recesses with a depth of 30 µm and not yet fixed. The upper magenta layer is lost and the lower yellow layer appears in the 1 mm-square area of recesses seen in the center of the photo, where the low secondary transfer efficiency is reproduced at the recesses. The secondary transfer efficiency was calculated by the ratio between the areas of magenta and yellow at the area of recesses in the photo of the non-fixed image. Figure 4 shows the results of measuring the dependency of secondary transfer efficiency on the depth of recesses. The secondary transfer efficiency decreases in both of the ITBs as the depth of the recess increases, and is higher in the two-layer ITB than in the PI ITB.

Study model

Figure 5 shows the study model for considering mottled images. In a secondary transfer process the following relationship needs to be satisfied for the toner (negative charged) located at a recess on an ITB to be transferred:

$$Fa < Fe \qquad (1)$$

where, E is the electric field, F_a toner adhesion force, and F_e electrostatic force by the electric field E. We examined the influences of the toner adhesion force and electro-physical quantities (relative permittivity and electric conductivity) of ITBs on the extent of mottled images for the two-layered ITB and PI ITB.

Toner adhesion force

In order to take account of the influence of the primary transfer process when measuring the toner adhesion force for analyzing mottled images, it is necessary to measure the adhesion force of the toner transferred on an ITB in the primary transfer process, and also to measure the toner adhesion force on a wide variety of ITBs. Therefore, we developed a measurement device that meets these requirements.

Measurement method

A schematic drawing of the device for measuring toner adhesion force F_a is shown in Fig. 6. The measurement was carried out by using a separation field method and a direct observation method [2]. To apply an electric field to the toner, the voltage was applied between an ITB carrying toner and a glass plate facing the ITB. The measured sample was prepared by transferring toner onto the ITB in the primary transfer process in a printer. In order to accurately measure toner adhesion force F_a to the ITB, the amount of toner transferred onto the ITB was controlled to 0.17 mg/cm^2 so that the toner particles could remain isolated from each other. An indium tin oxide (ITO) film was formed on the glass plate as a transparent electrode layer, and a polycarbonate film was formed on the ITO film as a transparent insulator layer. The electric field was changed by moving the ITB toward the glass plate to change the distance between the ITB and the glass plate while the voltage was applied by an external power source. The voltage was set at approximately 500 V to suppress discharging between the ITB and the glass plate. The number of toner particles that moved from the ITB onto the glass plate was counted by using a high-speed camera for each of various distances between the ITB and the glass plate. Figure 7 shows typical photographs captured by the high-speed camera. The bright spots are the toner particles that moved and reached the glass plate. The number of toner particles that reached the glass plate divided by the number of toner particles transferred onto the ITB was defined as the toner flight ratio. The toner adhesion force was calculated by fitting using the dependency of the toner flight ratio on the distance between the ITB and the glass plate, and the toner charge amount [µC/g], toner diameter [µm], and toner amount [mg/cm^2], which were measured by other means.

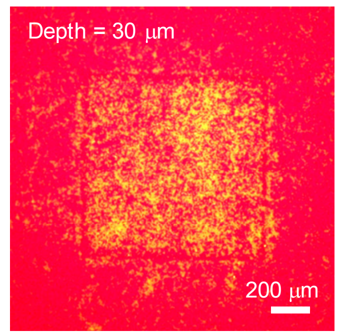

Figure 3. *Mottled image on a sculpted sheet*

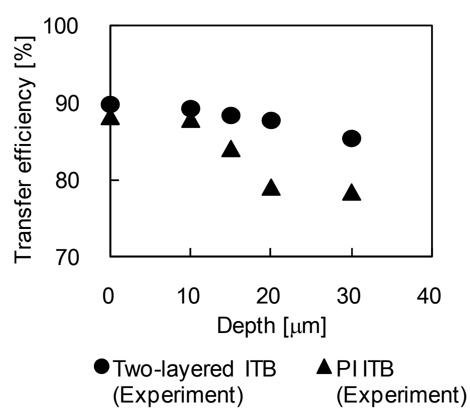

Figure 4. *Relationship between valley depth and secondary transfer efficiency*

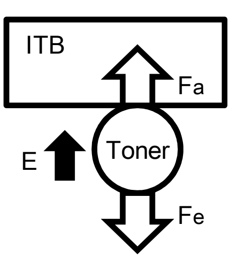

Figure 5. *Model of mottled image*

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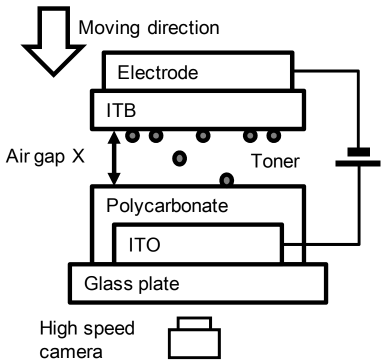

Figure 6. *Experimental system*

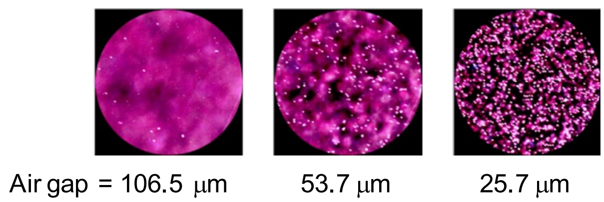

Figure 7. *Observed images of flying toner*

Fitting method

The toner adhesion force F_a was calculated by obtaining, from electric field simulation, the distribution of toner adhesion force F_a that most exactly fitted the measured dependency of the toner flight ratio on the distance between the ITB and the glass plate. Table 2 shows the parameters used in the simulation. This fitting assumes, referring to the distribution of toner adhesion force [3] given in a previous report, that the distribution of toner adhesion force F_a is represented by *f(x)* as given below, in which the common logarithm of the toner adhesion force F_a has a normal distribution:

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{(\log x - \log F_{ad})^2}{2\sigma^2} \right) \tag{2}$$

where, F_{ad} represents the median of toner adhesion force and σ represents the standard deviation of common logarithms of toner adhesion force. The distribution of toner adhesion force is hereafter represented by $\{F_{ad}, \sigma\}$. Figure 8 shows an example of the distribution of toner adhesion force to a PI ITB calculated by fitting. In this case, the distribution of toner adhesion force is determined as {70 nN, 0.7}.

Figure 9 shows the results of measuring the toner adhesion force to a two-layered ITB and a PI ITB. It is verified that F_{ad} is lower for the two-layered ITB than the PI ITB.

Table 2 Parameters for electric field simulation

	Permittivity	Conductivity [S/m]	Thickness [μm]
Two-layered ITB (Surface layer / Base layer)	70/40	$1\times10^{-8}/6\times10^{-9}$	3/70
PI ITB	70	1×10^{-8}	75
Polycarbonate	3	0	17
Toner layer	2	0	–
	M/S = 0.17 mg/cm^2, Q/M = −17 μC/g		

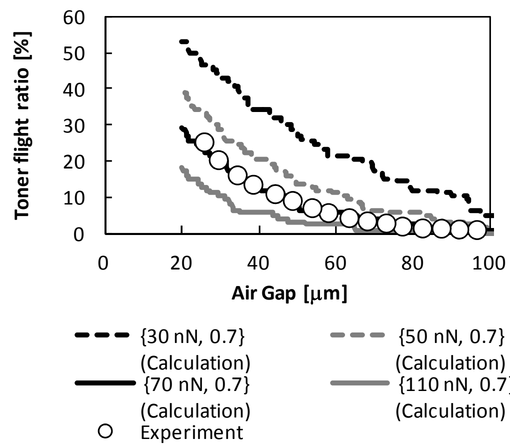

Figure 8. *Example of a fitting result*

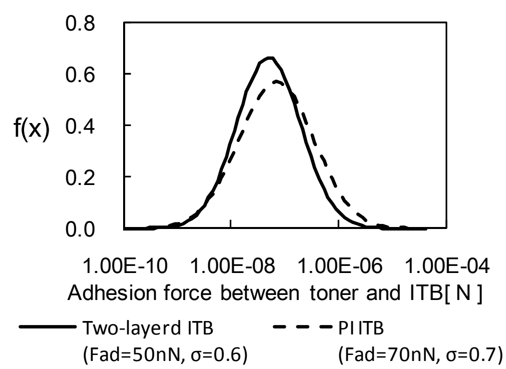

Figure 9. *Toner adhesion force to ITB*

Secondary transfer process simulation

The contribution of toner adhesion force F_a and the electro-physical quantities of ITBs to the extent of mottled images between the two-layered ITB and the PI ITB was studied by simulating the secondary transfer process.

Simulation method

In this study, the secondary transfer process was simulated by a combination of structural calculation and electric field calculation. First, the deformed shapes of members at the transfer nip were obtained by structural calculation, and then an electric field calculation model was built on the basis of the deformed shapes [4]. The electric field calculation includes four steps: calculation of charge transfer by electrical conduction, calculation of charge transfer by discharging, calculation of toner motion, and the charge transfer processing associated with the motion of substances. These steps were iterated until the potential distribution and toner motion became stable to obtain a solution. The charge transfer by electrical conduction was calculated based on Ohm's law and the charge transfer by discharging based on Paschen's law. Figure 10 shows a general view of the calculation model and enlarged views of the nip cross-sections at (a) a plateau area and (b) a valley area (recess). A different calculation model was employed for the individual depth of a recess on the sculpted

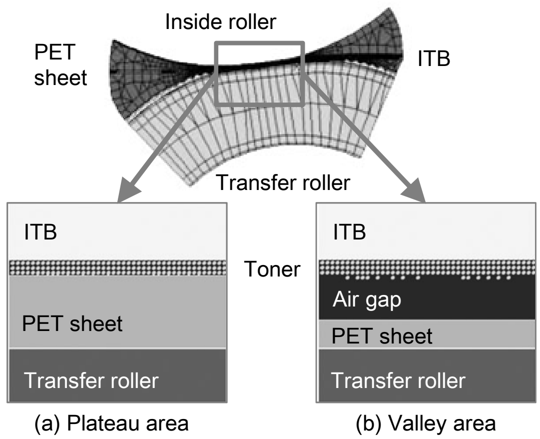

Figure 10. Secondary transfer process simulation model

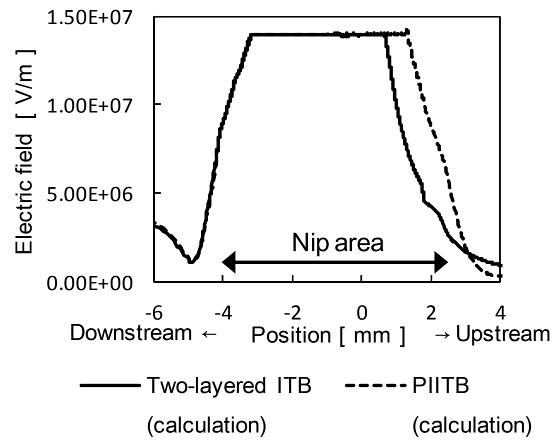

Figure 12. Comparison of transfer electric field

sheet. Table 3 shows the parameters used in the simulation. The adhesion force between toner particles was assumed to be a constant (3 nN). The values shown in Table 2 were used as the ITB parameters.

Table 3 Parameters for secondary transfer process simulation

	Permittivity	Conductivity [S/m]	Thickness [µm]
PET sheet	3	0	125
Transfer roller	66	5×10^{-8}	4000
Toner layer	2	0	-
	M/S = 1.2 mg/cm^2, Q/M = −17 µ/g, Adhesion force (toner to toner) = 3 nN		

Simulation results

Figure 11 shows the simulation results of the secondary transfer process superposed on the measurement results of the dependency of secondary transfer efficiency on the depth of recesses shown in Fig. 4. The simulation reproduced the tendency of the secondary transfer efficiency to decrease as the depth of recesses increases in both of the ITBs, and the generally higher secondary transfer efficiency of the two-layered ITB than that of the PI ITB. Figure 12 also shows the electrical field in the air layer at the secondary transfer nip has no difference between the two-layered ITB and the PI ITB.

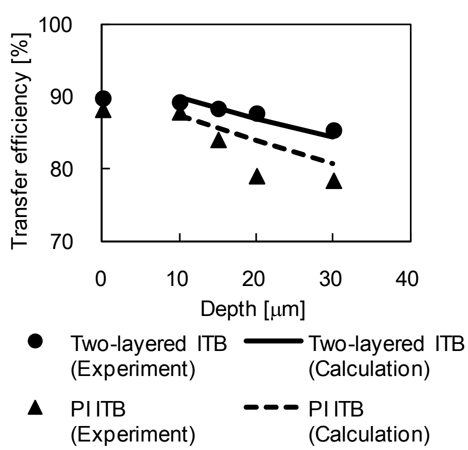

Figure 11. Comparison between experiments and simulations

The simulation results also revealed that, if the same toner adhesion force F_a is given in the simulation, the same secondary transfer efficiency is obtained regardless of the differences in electro-physical quantities of ITBs. Accordingly, it is considered that the toner adhesion force F_a contributes more to the extent of mottled images than the electro-physical quantities of ITBs.

Conclusions

This study revealed that the toner adhesion force F_a, not the electro-physical quantities of ITBs, contributed to the improvement of mottled images by the two-layered ITB in comparison with the PI ITB. It also found that the extent of mottled images of various ITBs can be evaluated by measuring the toner adhesion force to the ITBs and that the mottled image phenomenon can be reproduced by calculation.

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Author Biography

Yasunari Kobaru received his M.S. degrees in Physics from Kyushu University, Japan in 1993. He joined Canon Inc. in 1993 and has been engaged in the development of electro-photography.