Effect of transfer roller surface profile on discharge mark

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Abstract

In this report, we discuss the reason why transfer roller surface profile affects the discharge mark, and propose a new roller model for numerical simulation. Our observation has revealed that the discharge mark depends on the surface profile of transfer rollers, the conventional foam roller, smooth roller which has a smooth surface made of high polymer materials upon a foam roller, and the rough sanding roller which has the sanded surface of smooth roller. To make its dependence clear, we experimented with the electric charge distribution at transfer nip area focusing on the surface profile of the roller. Then, we build "Surface layer model" consisting of base-layer and surface-layer. The numerical simulation of electric field using this model made it clear that roller surface profile affects the discharge mark.

Introduction

Toner adhered to the transfer roller surface contaminates the back side of a media in transfer process. One of the proposed solutions to address this issue was to coat the surface of the transfer roller with protective materials such as resin tube and remove the toner attached to its surface by cleaning member such as the cleaning blade [1]. As one sample of the above proposed rollers, we used a transfer roller which has the smooth surface made of PFA tube and studied to see if discharge mark is observed on the printed image. As a result, discharge mark caused by the separating discharge is acknowledged. On the other hand, the level of discharge mark was improved by sanding PFA surface of the roller. Conventional knowledge cannot explain the differences in the level of discharge mark of those rollers. Given this situation, it is expected we will be able to take into account the roller surface profile in designing the transfer roller, if the cause of those differences are specified.

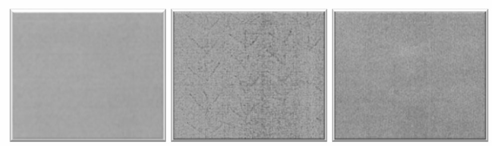
This report explains why the level of the discharge mark is changed by the surface profile of the transfer roller, using outcomes from the experiment in discharge on the transfer nip area and numerical simulation with the new roller model.

Experiment with the Laser beam printer

We compared the transfer performance of the existing foam roller to that of the new roller to understand the characteristics of the new secondary transfer roller. The foam roller is the one of which roller shaft (φ 12) is coated with a 5mm elastomer, and the new roller has a 50μm thickness PFA tube coating the foam roller (hereinafter "smooth roller"). In addition, we focused on the surface profile of transfer roller, and we prepared a roller which has the surface profile similar to the foam roller, which we sanded the surface of the smooth roller in rotation direction with sandpaper #100 (hereinafter "sanding roller"). There was a difference of the surface profile between smooth roller and sanding roller, but no significant difference in basic properties, such as the hardness and electric resistance, was acknowledged (Table1), and the electric current-voltage characteristic which is the index of the transfer characteristic, was about the same.

Table1 Roller properties

	Foam roller	Smooth roller	Sanding roller
Composition	foam elastomer	PFA tube	Sandpaper #100
Electric resistance	Volume : 7.8 (logΩ)	Volume :8.2 (logΩ) Surface :12.0 (logΩ/□)	
Hardness	35° (Asker C)	40° (Asker C)	



Left: Foam roller, Middle: Smooth roller, Right: Sanding roller
Fig1.Discharge mark

When we used those rollers and a Polyethylene Terephthalate sheet (hereinafter "PET sheet"), the media which had a high resistance, the level of the discharge mark was different, as shown in Fig.1. It was known that this discharge mark is caused by separating discharge and subsequent creeping discharge because of the negative charge density in total charge transfer material after the secondary transfer process, and also the quantity of the negative charge density is larger and then the level of discharge mark is worse [2]. The result of this experiment showed that the discharge mark of smooth roller was more visible than foam roller and sanding roller. From this result, as we focused before experiment, it is assumed that the difference of this discharge mark depended on the surface profile of the roller.

Quantity of electric charge of transfer sheet

We examined the total electric charge density of PET sheet in each roller to clarify the relationship between surface profile of the transfer roller and the level of discharge mark.

At the first procedure we performed secondary transfer of white image to the PET sheet to show it in upper part of Fig.2. The second procedure, we let the sheet after the secondary transfer process adhere on a metal plate. The third procedure, we measured the surface electric potential with a surface electrometer. And we performed these procedures for the top and back side of the sheet, and calculated electric charge density from each surface electric potential and PET sheet thickness. Then, the surface of metal plate was soaked in ethanol, and the potential of the reverse side to measurement was grounded and we measured the correct surface electric potential caused by only an electric charge of the measurement side.

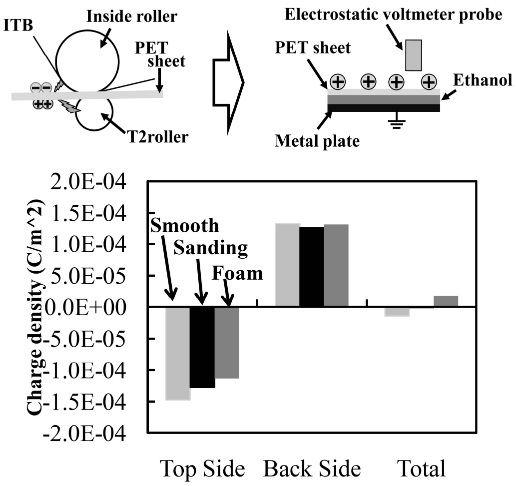


Fig.2 The measurement model and charge density

The lower part of Fig.2 shows the measurement result of the electric charge density on PET sheet. The charge density of foam roller was positive biased, and the charge densities of smooth and sanding roller were negative biased. In transfer process, excess of positive charge is neutralized by the static charge eliminator after the secondary transfer process, so that it does not become factor of discharge mark. Therefore noteworthy point is that the charge density of sanding roller is closer to neutral than smooth roller. This represents the discharge mark observed in this experiment is according to the conventional knowledge.

The surface profile of transfer roller and the discharge distribution at the near nip area

Subsequently we focused on the discharge as the factor of charge density difference, and decided to examine the different of discharge at the near area of secondary transfer nip.

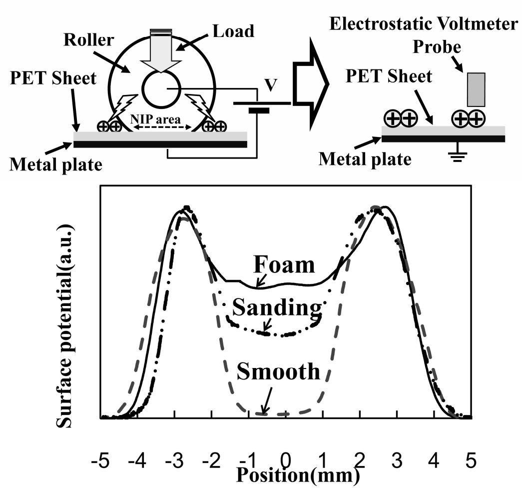


Fig.3 The measurement model and surface potential distribution

For actual experiment, we examined the relationship between difference of the discharge distribution at the near nip area and surface profile of the rollers by the measurement system shown in upper part of Fig.3. At the first procedure we let PET sheet adhere on the grounded horizontal metal plate. The second procedure, we added a load of the actual machine and applied a voltage to the shaft of the roller. The third procedure, we pulled up the roller while applying appropriate voltage in order to cause no discharge. The fourth procedure, we measured the surface electric potential distribution with a surface electrometer. Applied voltage was 3kV and the transfer material in this experiment was the same as PET sheet of the experiment with laser beam printer.

The lower part of Fig.3 shows the measurement result of the discharge distribution. Horizontal axis shows the position which zero point is the center of shaft and vertical axis shows the surface potential. But the maximum value of the surface potential aligned for comparison of discharge distribution. The solid line is the foam roller result and dashed line is smooth roller result, and chain double-dashed line is sanding roller result. The flat electric potential distribution shown on the center corresponds to nip part of the roller, and the peak values correspond to air gap of roller nip area neighborhood. The discharge distribution at near nip area showed no significant differences with each roller, but the electric potential in nip area of smooth roller was approximately 0, but the other two roller's potential increased in this area.

It is assumed that contact resistance of foam roller and sanding roller is higher than smooth roller because the contact area of two rollers is less than smooth roller, therefore it is unlikely that potential increases in nip area is caused by the injection of electric charge. In addition, it is assumed that the imparted charge of high resistance transfer material is considered to be dominated by the discharge than the injection, so it is reasonable to assume potential increase in nip area in this experiment is caused by the discharge.

Consequently, the reason for different potential distribution with each roller is considered as described below.

The peak values of the potential distribution at the near nip area are caused by the discharge between the PET sheet and the top surface of the roller with each roller. So it caused no significant difference of distribution.

The difference of the potential distribution in nip area is caused by the difference of the surface profile with each roller. Smooth roller is in close contact with the PET sheet for a smooth surface, so the discharge does not occur in the nip area and the potential distribution in nip area is zero. In contrast, other two rollers have air gap between the valley area of the roller surface and the PET sheet for rough surface, so the discharge occurs in the nip area and the potential distribution in the nip area is some values. Thus, it is considered that the difference of potential distribution with each roller is caused by the surface profile.

Therefore it is assumed that the different level of discharge mark in this experiment with laser beam printer is also caused by the discharge in the nip area depended on the roller surface profile.

To focus only on differences of surface profile as the roller parameter, the following is discussion about the difference between smooth roller and sanding roller.

In this report, we assumed "Surface layer model" as shown in Fig.4. This model consists of three layers and occurs the discharge in the nip area depended on the roller surface profile. From the surface the first layer is surface-layer consisted of air and PFA that is sanded, the second layer is base-layer consisted of PFA bulk that is a part of PFA tube not to be sanded, and the third layer is bulk-layer consisted of foam elastomer.

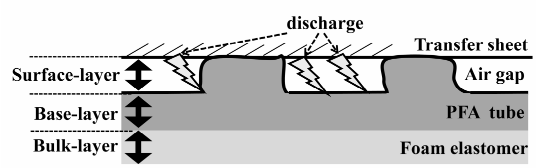
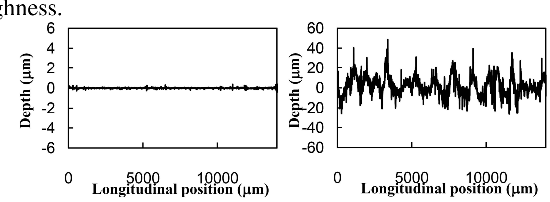


Fig.4 Surface layer model

The construction of the simulation model

We considered simulation model based on assumed "Surface layer model" to calculate the roller which have rough surface. Because of "Surface layer model" was based on the surface profile, we decided that the parameter of each layer based on its results. Then, by comparing experiment with simulation about the discharge distribution at the near nip area with each roller, we validated the assumed simulation model. The simulation of this report calculated the detailed nip shape of the each member by the structural calculation. And it calculated electric field by FEM (Finite Element Method) mesh based on the shape [3]. The electric field calculation stood on ohm's law and Paschen's law about charge transfer.

We measured the surface profile of each roller with a laser microscope. Fig.5 shows the measurement result of the depth profile of two rollers. Horizontal axis shows longitudinal position of the roller and vertical axis shows depth direction. The surface of smooth roller was very smooth according to the assumption. And the surface of sanding roller had waviness with small surface roughness.



Left: Smooth roller, Right: Sanding roller

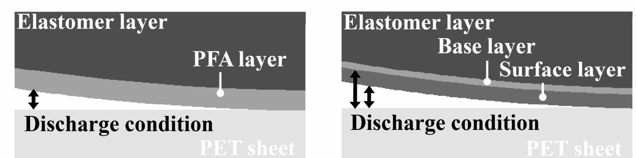
Fig.5 Depth profile of sanding roller

For smooth roller we constructed the simulation model consisted of two layers and not dividing PFA tube because of smooth surface. From the shaft direction the first layer was elastomer layer consisted of foam elastomer, and the second layer was PFA layer consisted of PFA tube. And we gave the conventional discharge condition between surface of PFA layer and surface of PET sheet.

For sanding roller we constructed the simulation model consisted of three layers to divide PFA tube according to measured waviness because of rough surface. From the shaft direction the first layer was elastomer layer consisted of foam elastomer, the second layer was base-layer consisted of PFA bulk that was a part of PFA tube not to be sanded, and the third layer was surface-layer consisted of both air and sanding PFA that was a part of PFA tube. In this report, we divided PFA tube when converting roller shape into the FEM mesh after structural calculation. Thus, the roller shape itself did not give the difference with two rollers. And we gave two discharge conditions. The first condition was conventional discharge condition between roller surface and transfer sheet surface, in this calculation between surface of surface-layer and surface of PET sheet surface. In addition, the second condition was discharge condition between surface of base-layer and surface of PET sheet surface. The assumed "Surface layer model", which media was imparted charge in the nip area by the discharge when the electric field intensity was sufficiently large, was embodied by this second discharge condition.Fig.6 shows FEM model for electric field calculation about two rollers, and Table2 shows properties for calculation.

Table2.Calculation condition

T2 roller		Permittivity	Electro conductivity
Elastomer layer		80	3 ×10^{-8} (S/m)
Smooth	PFA layer(50mm)	25	9 ×10^{-11} (S/m)
Sanding	Base layer(15mm)	25	9 ×10^{-11} (S/m)
	Surface layer(35mm)	1	9 ×10^{-12} (S/m)

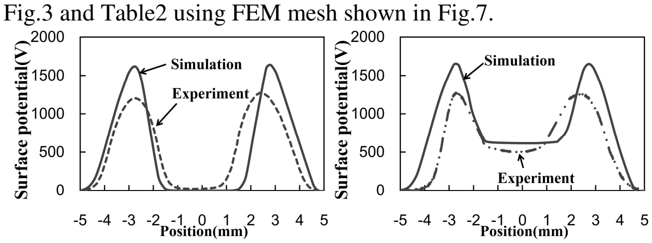


Left: Smooth roller, Right: Sanding roller

Fig.6 Calculation model of smooth roller

Basically, the parameter of each layer shown on the above table was actual measurement value. But the parameter of sanding roller based on "Surface layer model" was separately fixed. The parameters of base-layer were set the same value as the PFA tube, because we defined base-layer as a part of PFA tube not to be sanded. And the permittivity of surface-layer set 1 which was the same value as air due to discharge in the air gap which is present in actual this layer. The electro conductivity of sanding layer set a value of 10% of PFA tube considering the ratio of contact.

Fig.7 shows the results of experiment and simulation of the discharge distribution at the near nip area with two rollers. Each result of simulation shown in Fig.8 was the result of calculating the potential distribution of charge density considering the resolution of electric voltmeter used by the experiment. And the charge density of PET sheet was calculated in accordance with the experimental conditions and the calculation conditions shown in Fig.3 and Table2 using FEM mesh shown in Fig.7.



Left: Smooth roller, Right: Sanding roller

Fig.7 Surface potential distribution of Smooth roller

The peak values of the near nip area had the difference at the same level between simulation and experiments with both foam roller and sanding roller, but the difference of the electric potential distribution in the nip was well replicated. It can to be said that assumed simulation model was reasonable by this result.

The validation of Experiment with the laser beam printer by simulation

By using the above simulation model, we conduct the validation to confirm if the discharge occurred in the nip area actually causes the difference in the level of discharge mark, that is, the difference in the final charge density on the media after the second transfer process. The calculation condition was the same condition as experiment with the laser beam printer. The flow of simulation was similar those shown so far. And the following compared, after the electric current-voltage characteristic of simulation was coincident with the experiment.

Fig.8 shows the results of the simulation with smooth roller. and sanding roller. Fig. shows the displacement of the discharge position at the upper part and the displacement of the charge density of the transfer material (PET sheet) at the lower part. The horizontal axis of each part is aligned. And the arrow shows a process direction on Fig.8 at the upper part.

Firstly, we explain the simulation result of smooth roller and how charge density of PET sheet changed and discharge occurred in a process direction. First, PET sheet constantly receives negative discharge, which is applied from intermediate transfer belt (hereinafter "ITB"), at the exit area of the nip and PET sheet is negatively charged. This is the result that the positive bias applied to the transfer roller works, and it starts when the PET sheet starts to separate from the ITB and continues until it starts to separate from the transfer roller. After that, PET sheet starts to be positively charged as the positive discharge is applied from the transfer roller. This is the result that the discharge works to neutralize the polarity of the PET sheet, which is negatively charged in the prior process, and it starts when the PET sheet stars to separate from the transfer roller. However, overall, PET sheet is negatively charged when the discharge process is completed. This is because the negative discharge is already applied to PET sheet at the exit of the nip area before the positive discharge starts to be applied to it. Basically, a media is polarized by the discharge which is applied in first at the exit of the nip area, as the intensity of the electric field depends on the distance from the nip, the intensity is larger as closer to the nip and the amount of charge which is imparted by the discharge also increases accordingly.

Secondly, we explain the simulation result of sanding roller. For the sanding roller, the discharge in the nip area occurs by using the simulation model based on "Surface layer model" before PET sheet reaches the exit of the nip area. And PET sheet is charged positively by this discharge. The state of the discharge towards the downstream of the nip area is similar to smooth roller, but the final charge density of PET sheet is more positive than with sanding roller than smooth roller. This difference occurs as PET sheet reaches the exit of the nip area being positively charged in the nip.

Fig.9 shows the final charge density of PET sheet after the second transfer process, which is simulated and experimented above, is completed. Although the values are not exactly the same, both on two rollers, the results obtained from experiment and simulation showed the same tendency in the degree of the charge density on top/back side and total of PET sheet.

Therefore, the calculated model based on the above-explained simulated "Surface layer model" enabled us to simulate how the differences due to roller surface profile would affect on the charge density of the media, in other words, the level of the discharge mark, on the actual unit.

Conclusion

In this report, we have studied to verify the reasons that the discharge mark level changes along with the surface profile of the transfer roller. Those studies have revealed the discharge in the nip area, which differs depending on the roller surface profile, causes the difference in charge density on the media, resulting in a difference in the level of the discharge mark among rollers with different surface profile. And the calculation based on the new roller model enable us to take into account the roller surface property in the design and the simulation of the transfer roller.

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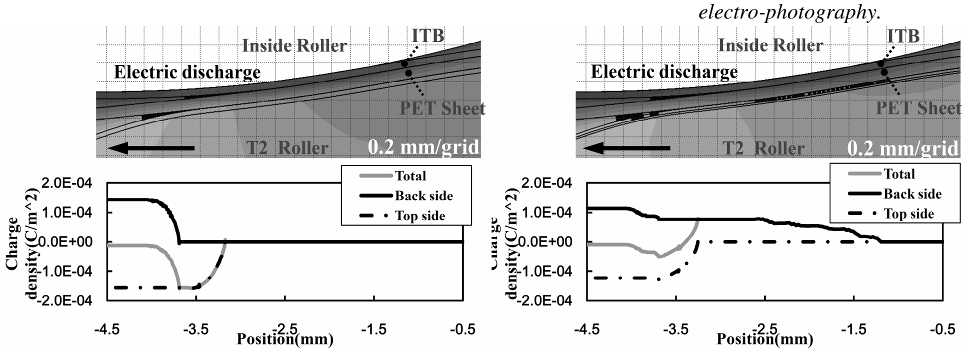
Author Biography

Ryosuke Hamamoto received his B.S. and M.S. degrees in Applied Physics from Tohoku University, Japan in 2003, 2005, respectively. He joined Canon Inc. in 2005 and has been engaged in the development of electro-photography.



Left : Smooth roller

Right : Sandign roller

Fig.8 Calculation results

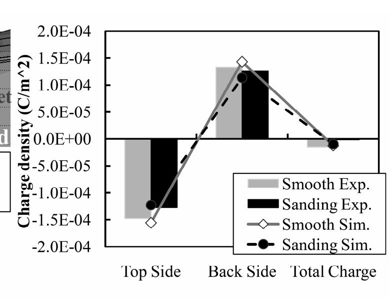


Fig.9 Calculation of the charge density