Paper Modeling in Transfer Process Simulation

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Abstract

When paper passes through a transfer station the paper is electrically charged. The charged paper sometimes sticks to an ITB or a transfer roller and causes a paper jam. A simulation model was constructed to examine the amount of charge on the paper. The modeled paper consisted of one base layer and two surface layers and the thickness and electrical properties of each layer were determined experimentally. This modeled paper was applied to a simplified transfer system and the current through the paper was calculated. The calculated results agreed well with the experimental values. In addition, it was revealed that the electrical properties of paper in a strong electrical field are determined by the discharge between paper fibers a microscopic distance apart.

Introduction

A transfer process in electrophotography has a problem of separation failure in which a piece of paper or other printing media electrostatically adheres to structural members such as a transfer roller. The failure is considered to be caused by the paper itself being charged from discharges from other parts when running through a transfer process.

The separation failure was examined and reported, for example, in a sheet transport simulation by Sasaki, et al.[1] However, their simulation was with respect to a PET sheet as an alternative to paper, and there was no examination of paper.

In this report, to examine the paper separation phenomenon, models capable of predicting the amount of charge accumulating on the paper were constructed to simulate a transfer process. Further, the phenomenon taking place inside the paper when a high voltage was applied was also considered in the modeling of paper.

Modeling of conductivity distribution

Paper employed for the examination and measurement environment

Standard office paper (Canon copy paper CS-814) is employed in the examination. The paper has a basis weight of 81.4 g/m^2, and a thickness of 95 μm.

As the paper characteristics depend on the environment, two measurement environments were set; temperature of 296K and relative humidity of 50 % RH (the NN environment) and 296K and 5 % RH (the NL environment). The paper used in the experiments was placed in each environment for about three days in order to acclimatize it.

Layered structure of paper and definition of thickness

The shape of a paper surface, which is uneven, was measured. Figure 1 shows the result of a paper surface profile in an area of 4 mm × 16 mm, where the horizontal axis represents surface height with the positive direction to the front side of paper, and the vertical axis represents the normalized frequency. The left coordinate in the vertical axis represents frequency, and the right coordinate represents cumulative frequency from the negative direction. In the chart, the depth where the cumulative frequency becomes 0.5 is taken as 0 μm, and a depth of 0 μm is defined as the average level of the surface roughness.

Next, real contact points in the state when paper was in contact with another member were considered. A quarts glass plate was pressed onto paper at a pressure equivalent to that of a transfer roller in a printer device. The contact plane was observed through a confocal microscope, but the real contact points could not be recognized. This is considered to be due to the paper having such a high stiffness that the contact occurs only at small areas at the ends of individual paper fibers. From the idea and the result of the paper surface shape in fig. 1, paper in contact with another member was considered to be composed of a layer present under the average level and the fibers are considered to be uniform. Then a layer with fibers protruding from the average level participates in the contact process. In this report the former layer is defined as the base layer and the latter as the surface layer. Since paper has 2 surfaces, the model composed of a base layer and two surface layers and is defined as a three-layer model. Figure 2 shows a schematic diagram of the surface roughness of paper and the corresponding three-layer model.

The thickness of the surface layer was set to be 13 μm, taken as the height from the average level to the outmost ends of the paper fibers that contribute to the contact. The thickness of the base layer was set to be 69 μm by subtracting the thickness of the two surface layers from the total paper thickness of 95 μm.

Measurement of conductivity and dielectric constant of each layer

First, the conductivity and dielectric constant with respect to the whole sheet of paper, including surface layers and a base layer, were measured. A piece of paper was sandwiched by 50 mm diameter disk-shaped metal electrodes having a polished electrode surface, and a voltage was applied between the two electrodes. Next, the conductivity of the base layer was measured by spattering platinum onto both sides of the paper in 25 mm diameter circular areas facing each other, between which the voltage was applied. The average roughness of the surface on which platinum was spattered is equivalent to the average surface roughness, that is,

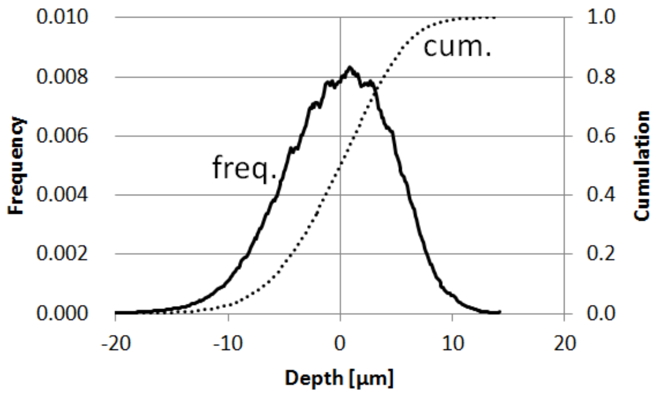

Figure 1. The frequency distributions of the surface profile

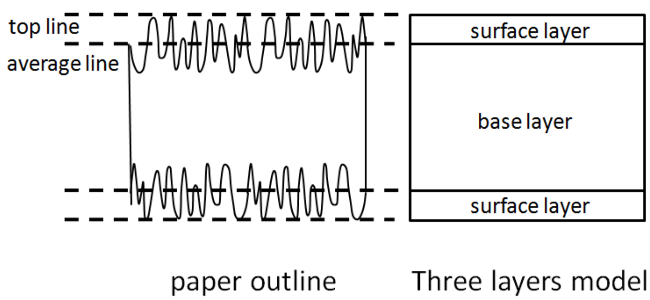

Figure 2. Outlines of paper modeling

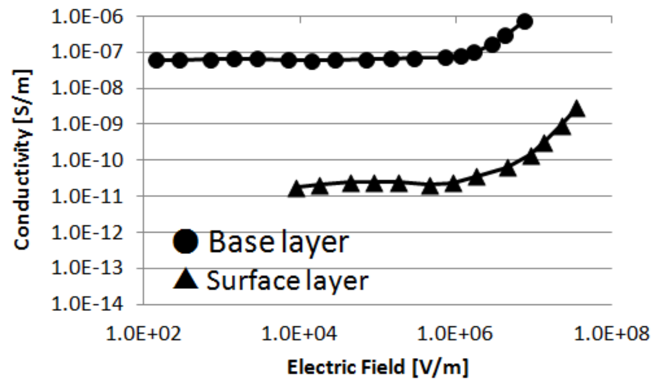

Figure 3. Conductivities of the base layer and the surface layer in NN

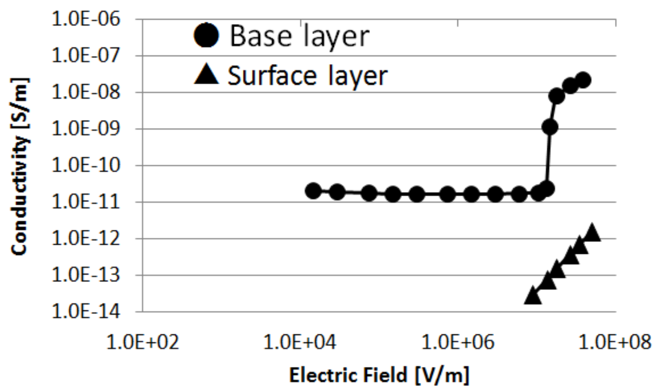

Figure 4. Conductivities of the base layer and the surface layer in NL

the surface of the base layer. Therefore, the measured values can be used directly as the conductivity of the base layer. Here, the resistance elements of the respective layers were assumed to be connected in series, and thus the conductivity of the surface layer was obtained by subtracting the conductivity of the base layer from the total conductivity.

Figure 3 shows the measurement results of base layer conductivity and surface layer conductivity in the NN environment with the horizontal axis presenting the electric field in each layer. The conductivity of each layer is almost constant up to an electric field of 1.0E+6 V/m, and the values are approximately 6.0E-8 S/m for the base layer and 2.0E-11 S/m for the surface layer. Conduction is considered to be carried out by water and impurities adhering to the fibers. Therefore the difference between conductivities of the surface layer and the base layer is considered to be caused by the difference in the number of fibers participating in the conduction. In the region of electric fields over 1.0E+6 V/m , the conductivities increase for both the base layer and the surface layer with the same gradient. The rise in conductivity is considered to come from the conductivity of the water and impurities depending on the electric field. In the region of higher electric field, over approximately 1.0E+7 V/m, dielectric breakdown occurred subsequently to discharge making measurements unattainable.

Figure 4 shows the measurement results of base layer conductivity and surface layer conductivity in the NL environment. The base layer has a conductivity of 2.0E-11 S/m in the region of low electric field. The lower conductivity in comparison with in the NN environment is considered to be due to the smaller amount of the water and impurities in the fibers participating in conduction. The conductivity of the base layer rises by approximately three orders when crossing over the electric field of approximately 1.0E+7 V/m. At that time an audible discharge was heard, which is considered to have occurred inside the base layer. Hereinafter, a discharge inside the base layer is referred to as an in-paper discharge. Meanwhile, the conductivity of the surface layer could not be measured in the region of 1.0E+7 V/m or lower. In consideration of the ratio of conductivity between the base layer and the surface layer in the NN environment, the region is considered to lay outside of the measurement limit. In the region over 1.0E+7 V/m the current gradually began to flow. Though there was no audible discharge, by taking into account the discharge generated in the base layer in the same electric field range, it is inferred that the current flowed by discharge.

The measurement of the dielectric constant of each layer was carried out as below. The dielectric constant of the base layer was obtained from the relaxation times measured in the plural applications of voltage increasing stepwise, by using the same measurement device as that for the conductivity. As a result, the dielectric constant of the base layer was 4.6 in both the NN environment and NL environment. Meanwhile, in consideration of the difference in conductivity of the surface layer and the base layer, the surface layer can be taken as being occupied almost completely by air. Therefore, the dielectric constant of the surface layer was assumed to be 1.0.

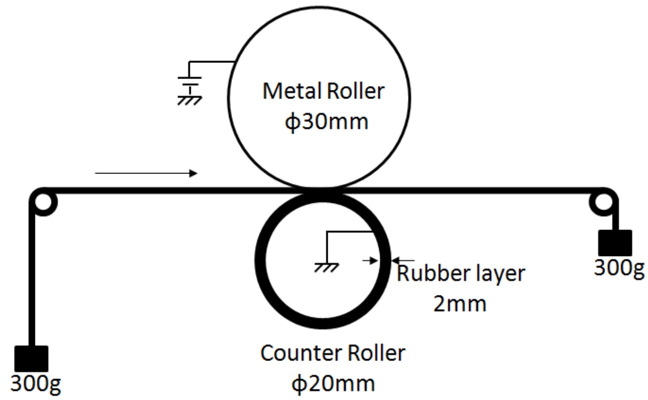

***Figure 5.** Comparison results of current-voltage characteristics in NN and NL*

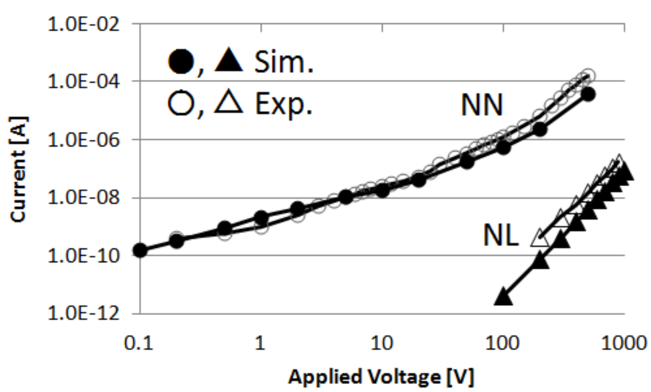

***Figure 6.** Outline of verification system*

Verification by static model

Figure 5 shows the results of the currents measured flowing through the 50 mm diameter metal disk electrodes sandwiching the paper in the NN and NL environments, in comparison with the calculation results from the three-layer model of the same system using the conductivities and dielectric constants of the base layer and surface layer. From the diagram, the calculated results are consistent with the experiments in both the NN and NL environments.

However, there was no audible discharge in the experiment in the NL environment. This fact shows that the in-paper discharge did not occur inside the base layer since the partial voltage on the base layer was lower than that on the surface layer. The results in the NL environment shown in Fig. 5, therefore, did not include any in-paper discharge. In an actual printer a separation failure occurs when an extremely high voltage is applied, and further the in-paper discharge has a great influence on the paper conductivity in high electric fields. From these viewpoints, the significance of the in-paper discharge and the modeling are examined in the next chapter.

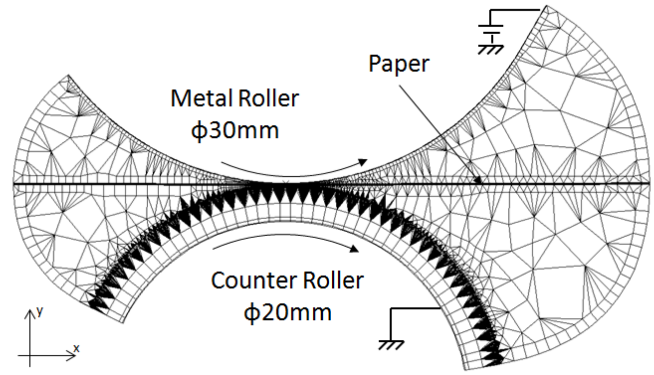

***Figure 7.** Mesh model*

Modeling of in-paper discharge

Experimental Method

The device simulating the simplified transfer process was used in the experiments. Figure 6 illustrates a schematic configuration of the device. A metal roller which had a smooth surface, a diameter of 30 mm, and a width of 50 mm was pressed by a counter roller, which had a semi-conductive solid rubber layer 2 mm thick coated on a metal core, at a force of 600 g-force. A paper ribbon 60 mm wide was inserted between the rollers and put under tension by two 300 g weights attached to both ends of the paper ribbon. The device was operated at a process speed of 0.1 m/s, while the metal core of the counter roller was grounded, the metal roller had a voltage applied, and the current was measured. The measurement was carried out in the NL environment with a voltage up to 4 kV.

Calculation Method

A two-dimensional finite element method was used for the simulation. Figure 7 is the mesh model constructed based on the experimental device shown in Fig. 6. Here, the paper consists of three layers, that is, the base layer 69 μm thick and the two surface layers 13 μm thick arranged on the both sides of the base layer. Discharge was assumed to occur between the metal roller surface and the upper surface of the paper, and also between the opposite roller surface and the lower surface of the paper. Each of the upper and lower surfaces of the paper was the average level of the surface roughness, that is, the surface of the base layer.

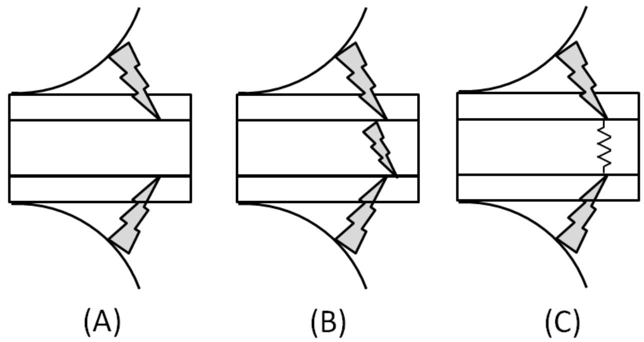

Figure 8. *Outlines of internal discharge models*

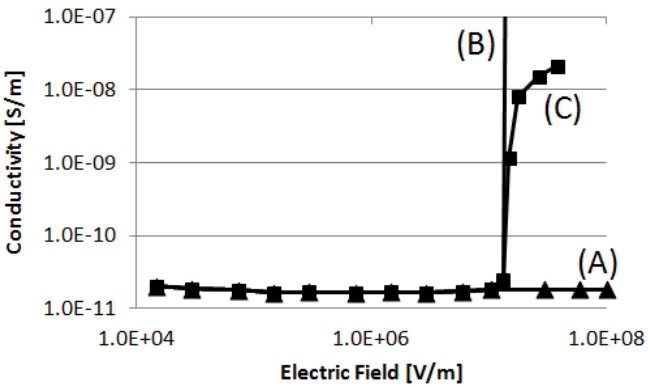

Figure 9. *Conductivities of the internal discharge models*

Three models were compared according to the ideas of conduction, to determine the in-paper discharge model. Figure 8 shows the schematics of the models, where the lightening symbols represent the discharge paths taken into account in the respective simulation models. Figure 8 (A) shows the model in which no in-paper discharge, only the conduction in fibers is considered. Figure 8 (B) shows the model in which the discharge occurs inside the base layer based on Paschen's law. Figure 8 (C) models the effect of discharge converted to the conductivity of the base layer from the measured charge of the in-paper discharge. The conductivity of the base layer in each model is shown in Figure 9, where the measured values shown in Fig. 4 are used since they go up to an electric field of 1.0E+7 V/m at which the in-paper discharge occurs. In the region of higher electric fields, the values extrapolated from the values in the range of lower electric fields are used for model (A), the conductivity is infinite in model (B) due to the conduction being performed by discharge, and the measured values shown in Fig. 4 are employed in model (C).

Results

Figure 10 shows the comparison between calculated values and experimental values of the current flowing through the metal roller with the applied voltage represented on the horizontal axis. The calculated value at 4000 V in model (A) is approximately 1/50 of the experimental value. The experimental value starts to rise at approximately 1500 V, but the calculated value in model (A) does not rise anymore. The analysis of the calculation results shows that

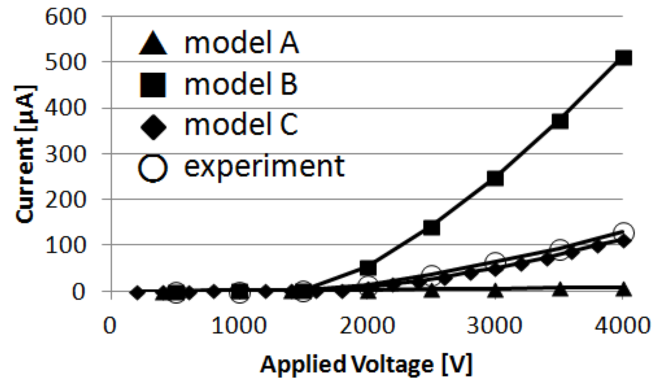

Figure 10. *Current voltage characteristics in NL*

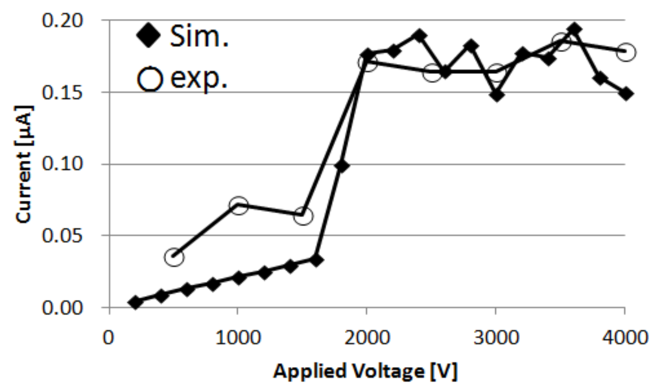

Figure 11. *Currents which flow into the paper in NL*

the discharge between a roller and the paper starts at approximately 1500 V, and that the charge, however, is accumulated on the paper surface. Basis on the difference in the current from the experimental values, it is considered that the charge is conducted inside the base layer in model (A).

The calculation results of model (B) show the rise of the current at approximately 1500 V is in a similar manner to the experiment. However, the current increases to about three times that of the experimental value at 4000 V.

The rise of the current, which cannot be seen in model (A), suggests that the current in the region over 1500 V is caused by the in-paper discharge. In the real in-paper discharge, however, the extension of discharge is considered to be inhibited by the paper fibers. Model (B) defines the in-paper discharge as the conduction by means of simple discharge, which is considered to cause the difference of the current in the high voltage region from the experiment.

The result of model (C) is in good agreement with the experimental values both in the rising point and the gradient of the current. The inhibition of discharge by fibers was precisely represented by converting the in-paper discharge into conductivity.

Figure 11 shows the comparison of the current carried on paper and flowing to the outside between the calculation using model (C) and the experiment. Both the current increase at approximately 1500 V and the current convergence to

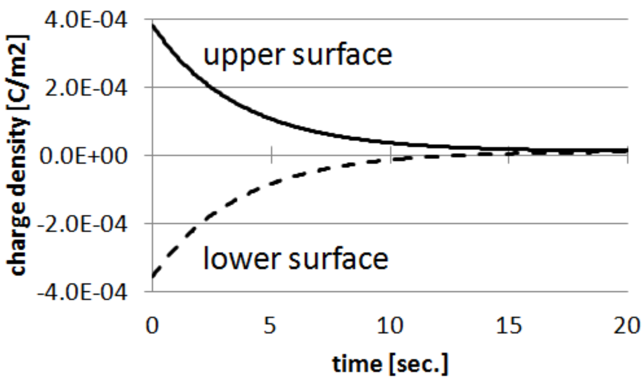

Figure 12. *Charge density decay in NL*

approximately 0.18 μA over 2000 V coincide with each other. The current that flowed into the paper was so weak to be about 0.2 % of the total current of the whole system, but the model reproduced the experimental results extremely well.

Figure 12 shows the calculation results of the decay of the charge from the paper in passing the nip applied with 4 kV as shown in Fig. 10 from the timing of just passing out of the nip. The horizontal axis represents the elapsed time after passing the nip, and the solid line represents the charge density on the upper surface of the paper, the initial value of which is 3.81E-4 C/m^2. The dashed line represents the charge density on the lower surface of the paper, the initial value of which is -3.55E-4 C/m^2. It is understood from the diagram that the positive charge on the upper surface of the paper and the negative charge on the lower surface of the paper combine and finally converge to a differential value. In this simulation, the time taken to decay to $1/e$ times the initial value is approximately 3.5 seconds. Such results are quite useful for predicting paper separation failure, image degradation caused by discharge, etc. occurring on the downstream side of a transfer process. This modeling allows these problems to be estimated.

Summary

The electrical behavior of a piece of paper in a transfer process was modeled for a sheet transport simulation.

1. The three-layer model in which paper was assumed to consist of a base layer and two surface layers was employed. The electrical conductivity and dielectric constant of each layer were obtained by measurement.
2. The experimental results obtained by using the device simulating a transfer process were combined with simulation results for consideration, which revealed that the in-paper discharge played an important role as a factor in determining the amount of charge on the paper.
3. The amount of charge discharged by in-paper discharge were measured and converted to electrical conductivities. The operation made it possible to reproduce the current flowing in a system and the amount of charge carried downstream on by paper in the simulation device.
4. The modeling made it possible to calculate the process of charge decay on the paper after the paper passed a transfer nip.

As mentioned above, the three-layer model considering in-paper discharge made it possible to predict the amount of charge on paper in a transfer process. The modeling can also be applied to thinner paper, coated paper, and the like.

References

[1] T.Sasaki, K. Yamamoto, T. Onishi, A. Sugiyama. T. Tomizawa and Y. Yoda, J. Imaging Sci. Technol., **54**, 3 (2010)

Author Biography

Seishirou Nasu received his M. E. degrees in Applied Physics engineering from Miyazaki University, Japan in 1999. He joined Canon Inc. in 1999 and has been engaged in the development of electrophotography by using numerical simulation.

