

Effects of Existing Air on Fusing Temperature Field in Electrophotographic Printers

Kazuki Takenouchi, Masahiro Samei, Takuo Shimokawa* and Kazuaki Kawakita*
Kyushu Institute of Design, Fukuoka, JAPAN
**Kyushu Matsushita Electric Co., Ltd., Fukuoka, JAPAN*

Abstract

Thermal properties are examined based on measured data for precise estimation of heat transfer phenomena in fusing region in electrophotographic printers. Measurement of the surface texture of paper indicates the existence of air due to the surface roughness of the paper, and the thickness of an equivalent air gap layer as a thermal resistance in heat conduction is evaluated based on the surface profile. The amount of air existing in a toner layer due to its porous feature is determined based on the particle arrangement and the diameter of toner particles, from which another additional thermal resistance due to air is evaluated. Numerical estimations of temperature field with and without the additional thermal resistance indicate that the introduction of the thermal resistance evaluated in this paper contribute to a marked improvement of the estimation. The importance of appropriate position for introducing the thermal resistance is also pointed out.

Introduction

Higher speed and quality of printing with lower energy consumption have been a principal technical goal for electrophotographic printers. Such performances mainly depend on heat transfer phenomena governing the functional efficiency of toner fusing process; their improvement thus requires clarifying the heat transfer phenomena in the fuser. A few experimental studies[1] have been reported on heat transfer in the fusing region, it seems to have difficulties in obtaining two-dimensional feature of the phenomena due to small dimension of the fusing region and high temperature; numerical approaches are expected to be powerful alternatives for obtaining thermal characteristics in the region.

The authors have been studying a numerical approach to estimate the above phenomena and some of the results suggest the existence of a high resistance in thermal conduction by a comparison of estimated results with that obtained by measurement[2]. In this paper, the thermal resistance will be related to air existing in the fusing region and evaluated based on geometrical characteristics of the members in the region.

Construction of Toner Fusing Region

A heat roller fuser of electrophotographic printers is illustrated in Fig.1. The fuser is composed of a heater, an aluminum heat roller with fluoride resin coated on its outer surface, deposited toner powder, a paper and a pressure roller composed of an elastic rubber and a stainless core. The two rollers are pressed against each other, between which a nip is formed for fusing process. In the fusing nip, it is clear that a certain amount of air is involved due to porous feature of toner layer and existence of surface roughness on the paper. Considering that the thermal conductivity of air, 0.030 W/(mK), is much smaller than those of toner material and paper, 0.151 W/(mK) and 0.080 W/(mK), respectively, the effect of existing air on heat transfer should be properly evaluated for the precise estimation of fusing temperature field.

Estimation of Amount of Air In Fusing Region

Air Existing In Toner Layer

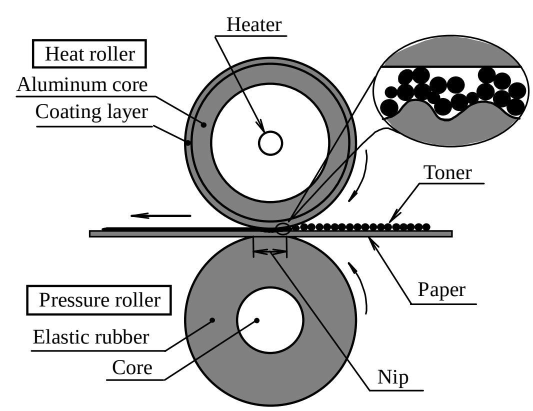


Figure 1. Schematic of fuser of electrophotographic printer

A SEM photomicrograph in Fig.2 shows the layer of unfused toner powder deposited on paper with medium image density. The observation of the photo indicates that the shape of the toner particles is almost sphere with a certain deviation of diameter, and their arrangement on the paper is properly regular in two-storied hexagonal closest packed lattice. Figure 3 summarizing the diameters of toner particles, d_t, by Coulter method indicates that the mean value of d_t is 7.6 μm with standard deviation σ of 2.3μm. When toner particles with the same diameter array in two-storied hexagonal closest packed lattice as shown in Fig.4, the thickness of the toner layer, δ_t, and the rate of porosity are geometrically calculated to be 13.8 μm and 0.334, respectively. The amount of air existing in the layer is then reduced into the thickness of an equivalent air gap layer, δ_{gt}, to be 4.6 μm. This means that the toner layer of 13.8 μm in geometrical thickness is thermally equivalent to the layers of air and solid toner material of 4.6 μm and 9.2 μm in thickness, respectively.

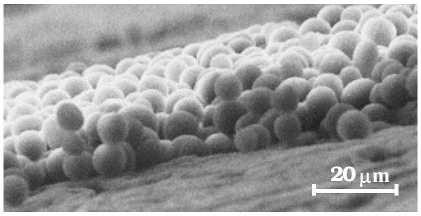


Figure 2. Toner particles deposited on paper

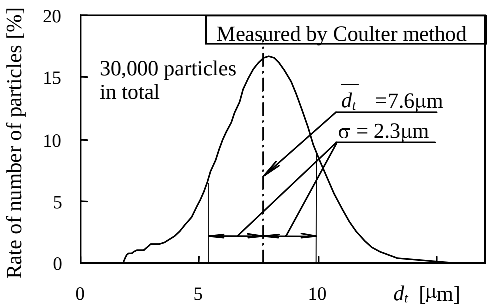


Figure 3. Distribution of toner particle diameter

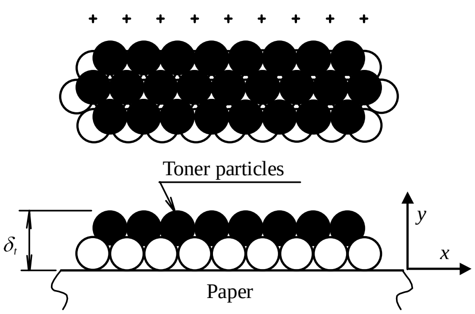


Figure 4. Schematic model of toner arrangement on paper

Air Existing In Paper-Roller Interface

Figure 5 shows a SEM photomicrography of the surface of a plain paper. Pulp fibers entangled non-directionally and hollows are clearly observed in the photo. When the surface is in contact with another, a certain amount of air is captured in the closed space between the two. To evaluate the property of the surface texture, the surface roughness is measured by a contact profile meter with ad hoc measuring force of 0.3 mN, and radius of stylus of 0.5 μm. The profiles of the surface roughness are shown in Fig.6 in (a) machine and (b) cross directions, and the main properties of the surface roughness, the maximum height of the profile R_y and the mean spacing of profile S_m, are listed in Table 1, where l is the sampling length. The results indicate that the properties of the roughness have no significant difference in the two directions; the paper is thus considered to have an isotropic feature.

To evaluate the amount of air existing in the surface roughness, two-dimensional rate of hollowed area is evaluated by numerically integrating the area enclosed by the surface roughness profile and the line of profile peaks. The result is presented as a ratio of the area to the rectangle one between the lines of profile peaks and valleys to be 0.46. As is presumed that the paper texture is isotropic, the ratio of hollowed space in three-dimensional roughness profile to the volume between the surfaces of profile peaks and valleys is estimated to be around 0.5 by extending the one in the two dimensional measurement. Then the thermally equivalent thickness of air gap layer is evaluated as δ_{gp}=5.7 μm in the same manner of that of toner layer.

When toner powder is deposited on the paper, profile of the toner layer surface is considered to be almost the same to that of the paper surface as illustrated in Fig.7 from the reason that the averaged mean spacing of the profile S_m of 117.5 μm, is much larger, about 15 times, than the mean diameter of toner particle. The thickness of air gap layer of 5.7 μm is then available on the both surface of the paper.

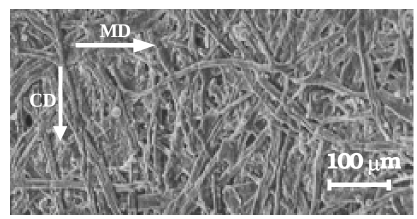
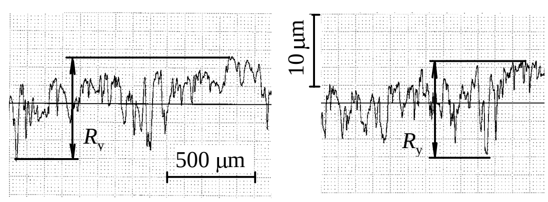


Figure 5. Surface texture of paper



(a) Machine direction (b) Cross direction
Figure 6.Profile of surface roughness

Table 1. Surface Roughness Properties

Direction	R_y [μm] (l [mm])	S_m [μm] (l [mm])
Machine direction	11.9 (2.5)	130.0 (0.25)
Cross direction	13.0 (2.5)	101.4 (0.25)
Average	12.5	115.7

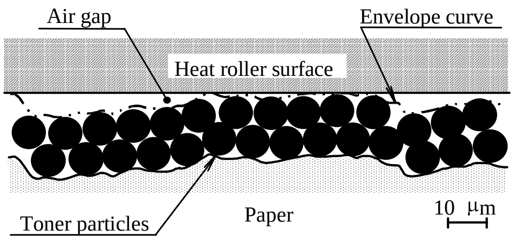


Figure 7. Schematic of air gap due to paper texture

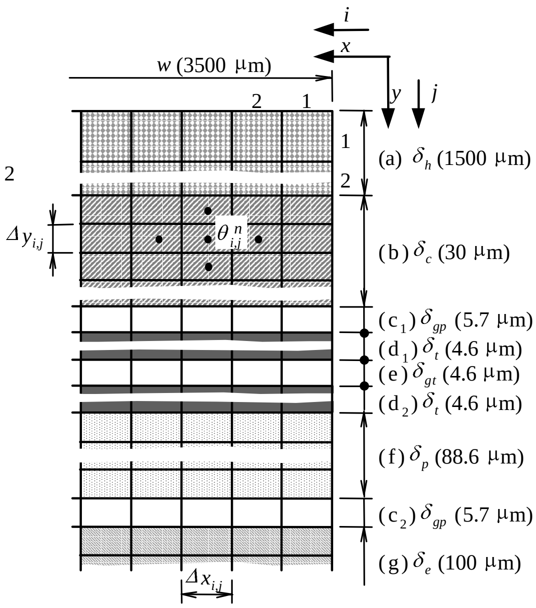


Figure 8. Computational grid

The thickness of the air layer is thus 11.4 µm in total on the both sides of the paper and the equivalent paper thickness with perfectly smooth surface is 88.6 µm.

Outline of Numerical Method

In the numerical estimation of temperature in fusing field proposed by the authors[2], the equation of two-dimensional thermal conduction is solved with ADI method[3].

Illustrated in Fig.8 is the computational grid on which the governing equation is discretized and solved. Vectors of heat flux are defined on the boundaries of each cell and scalars of temperature θ at the center of that. Boundary conditions to the computed region are constant heat flux incoming at the upper boundary (y=0) and adiabatic at the remaining three boundaries. The geometrical and thermal properties of the layer thickness δ, the thermal conductivity λ and the thermal capacity c of each layer are listed in Table 2. The layers are arranged in the order according to the actual construction of the fusing region and the air gap layers evaluated in the previous chapter are inserted into the corresponding layer or boundaries. The temperature of each cell is transferred to its adjacent outgoing cell synchronizing with the rollers' rotation. The characteristics in phase transfer of toner powder without having a distinct melting point is modeled with an equivalent melting point and a latent heat[2] illustrated in Fig. 9.

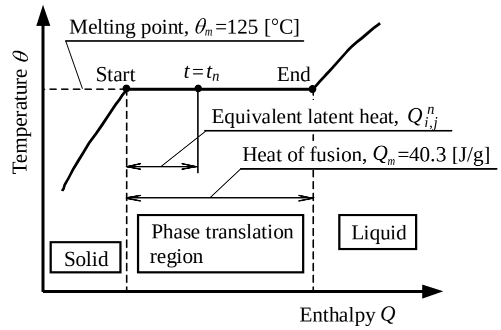


Figure 9. Phase transfer model of toner[2]

Table 2. Thermal Properties of Fuser Members

Layer	δ [µm]	λ [W/(m°C)]	c [MJ/(m^3°C)]
(a) Heat roller core	1500	228.6	2.50
(b) Coating layer	30	0.181	1.64
(c) Equivalent air layer	11.4	0.030	0.0012
(d) Toner layer	9.2	0.151	1.51
(e) Equivalent air layer	4.6	0.030	0.0012
(f) Paper	88.6	0.080	1.16
(g) Elastic layer	100	0.281	2.01

Results and Discussion

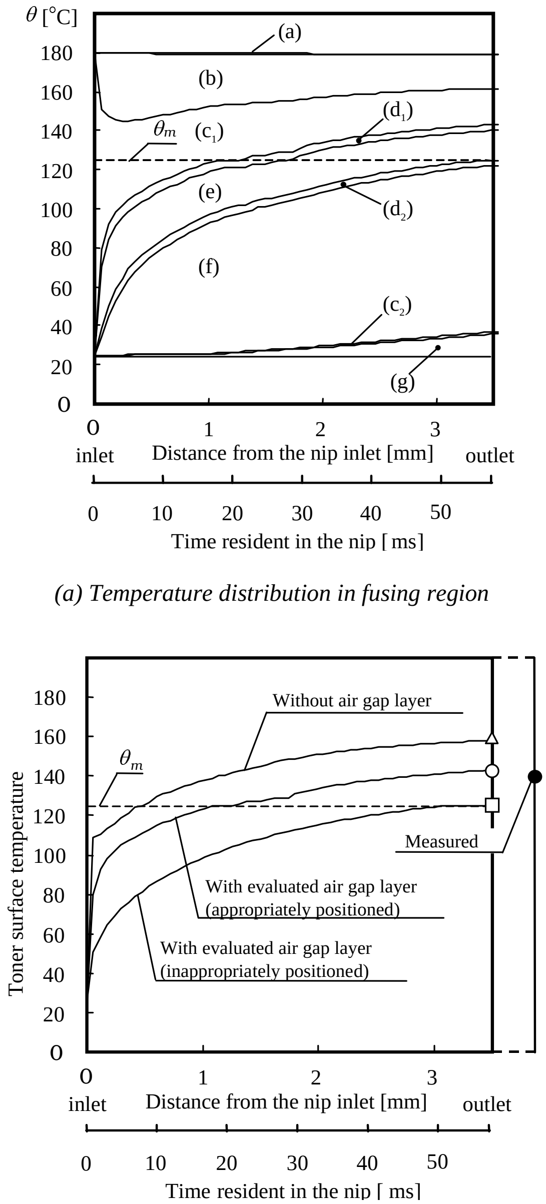
Figure 10(a) shows the estimated result of the temperature field in the fusing region with the air gap layers evaluated in the preceding chapter under the operating conditions listed in Table 3. It is found from the result that the temperature on the coating layer rapidly decreases to the minimum of 143°C at 0.3 mm behind the nip inlet (5 ms resident in the fusing nip), followed by a moderate recovery with the temperature rise of the lower members. The temperature of toner layer surface changes from 25°C at the inlet of the nip, the environmental temperature, to 143°C at the outlet through 125°C, the start of phase transfer of toner, at the 1.14 mm behind the inlet (19 ms resident in the fusing nip).

Table 3. Parameters in Calculation

Parameters	Values
Fusing speed, v	60 [mm/s]
Nip width, w	3500 [µm]
Heat flux from heater, q_h	31.9 [kW/m^2]
Heat roller temperature, θ_h	180 [°C]
Environmental temperature, θ_s	25 [°C]

In Fig.10(b), toner layer surface temperatures are compared on the differences in the thickness and the inserted position of the air gap layer due to toner porosity. Plotted in the figure by solid circle is the temperature[2] measured by infrared radiation thermometer just behind the nip outlet.

The experimental conditions were carefully adjusted to the ones employed in the numerical calculation and the toner is deposited uniformly on the whole surface of the paper.



(a) Temperature distribution in fusing region

(b) Effects of thickness and position of air gap layer

Figure 10. Estimated results of temperature field

Without considering the air gap layers, the estimated temperature at the outlet is 158°C, plotted by hollow triangle, higher than the measured one by 18°C, indicating the necessity of some additional thermal resistance in the region. The estimation with the air gap layers of 143°C, plotted by hollow circle, almost coincides to 140°C obtained by the measurement. The good agreement guarantees the availability of the evaluation of the thermal resistance by air existing in the fusing region and the reliability of the temperature field estimated by the numerical method.

Also shown in the figure by hollow square is obtained with positioning the air gap layer of the toner at the top of the toner layer. The two estimated results have distinct discrepancy each other, the latter giving lower estimation by 13°C to the measured one while the former offers a good agreement as described above. The comparison leads to the importance of appropriate position for introducing the equivalent air gap layers in addition to the correct evaluation of the thermal resistance.

Conclusions

For estimating the fusing temperature field in electrophotographic printers, resistances in thermal conduction due to air existing in toner layer and in surface roughness of paper are evaluated quantitatively based on their geometrical properties. The magnitudes of the thermal resistance are reduced into the thickness of equivalent air gap layers for numerical estimation of temperature field in fusing region. The evaluated values are discussed based on the temperature obtained by measurement. The results are summarized as follows:

(1) The amount of air involved in toner layer and in surface roughness of paper is evaluated based on their geometrical properties. The thermally equivalent thickness of air gap layers is calculated for the application in numerical estimation of temperature field in the fusing region.

(2) The numerical estimation with the above equivalent thickness of air gap layers offers a good agreement with that obtained by measurement. The fact indicates the availability of the evaluation of the thermal resistance due to air existing in the fusing region.

(3) The importance of appropriate position for introducing the equivalent air layer is also pointed out.

References

1. Mitsuya, T., Masuda, K. and Hori, Y., "Measurement of Temperature and Heat Flux Changes during the Fixing Process in Electrophotographic Machines", *Trans. ASME, J. of Eng. Ind.*, **118**, 150, (1996).
2. Samei, M., Shimokawa, T. et al., "Estimation of Temperature in Toner Fusing Field", *IS&T's NIP14 International Conference on Digital Printing Technologies*, (1998).
3. Peaceman, D.W. and Rachford, Jr., H.H., "The Numerical Solutions to Parabolic and Elliptic Differential Equations", *J. Soc. Ind. Appl. Math.*, **3**, 28, (1995).

Biography

Kazuki Takenouchi received his B.E. and M.E. in Mechanical Engineering from Kyushu University at Fukuoka, Japan in 1983 and 1985, respectively, and his Dr.Eng. in Mechanical Engineering from Kyushu University at Fukuoka, Japan in 1991. Dr. Takenouchi has been working for Kyushu Institute of Design, Fukuoka, Japan since 1989, where he is now a teaching and research staff, an associate professor. He has been majoring in computational mechanics and design engineering.

E-mail address: ktake@kyushu-id.ac.jp