Relationship between Thermal Conduction Process and Transient Temperature Response of Printing Papers in DTP Process

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Abstract

This study describes effects of a thickness of printing papers and a thermal conduction from the printing paper to a platen roller on a temperature transient response of the printing papers through 3 dimensional thermal conduction analysis. Especially, a level of the effects of these factors on the transient temperature response was evaluated. A 3-dimentional analytical model which was composed of the paper and a dot heater was prepared and a transient thermal conduction analysis was performed while changing the condition of heat leak from the paper surface opposite to the thermal head to the platen roller. In order to evaluate the transient temperature response of the paper, temperature rise at the heating point of the test paper after 1 second from the start of the heating was calculated. It is found that that the thickness of the paper and the level of the conduction to the platen roller affect the temperature response of the paper separately. In addition, the change of the thickness and the condition of the conduction also affects the level of the effects of the thermal diffusivity on the temperature response.

Introduction

Direct Thermal Printers (DTP) prints images by selectively heating thermal papers by using a thermal head which consists of lots of dot heaters (Fig. 1). In the recent years, there is a great demand of DTP to portable POS (Point-of-Sale) terminals. The printers for the POS terminals should be small in size while reducing the use of expendables such as toner cartridges. DTP printers can be miniaturized while decreasing the use of the expendables because DTP can produce images by using only thermal papers and heat from the thermal head. Therefore, DTP has been used for the printer of the POS terminals.

Several studies [1] – [4] have been investigated about printing technologies of DTP and heat transfer process when the DTP printing operates. However, as the printing device for the novel portable terminals, more decrease of a power consumption is strongly needed because a battery life should be prolonged. In addition, an improvement of printing quality and the color printing are also required. In order to advance the thermal printing process, the further investigation of printing process of DTP should be needed. Here, the printing quality and the power consumption of DTP process are generally dependent on thermal conduction process around the printers and the printing papers (Fig. 2). Therefore, an additional investigation about thermal conduction of DTP process may be effective for optimizing the structure of the DTP printer for achieving the improvement of the printing quality while downsizing the dimensions and decreasing the power consumption.

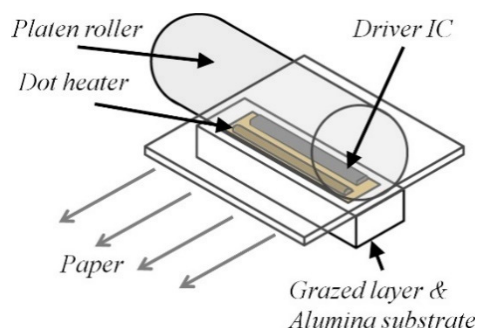

Figure 1. Schematic of the image of the thermal printing

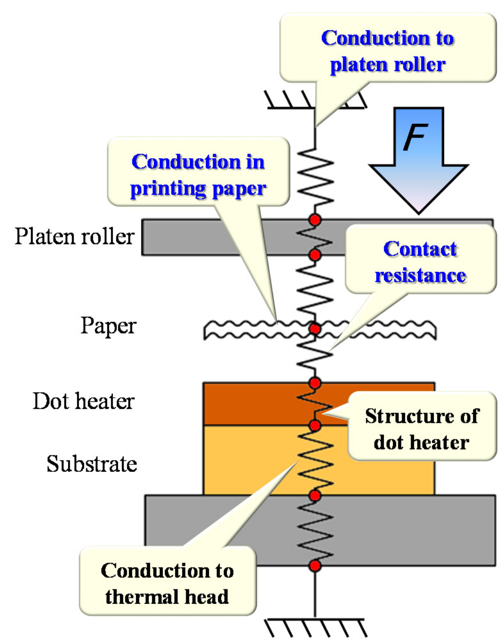

Figure 2. Factors affecting temperature response of the printing paper

From these backgrounds, our study aims to investigate a relationship between printing process of DTP and thermal conduction phenomena in order to improve DTP printers [5] [6]. In our previous research, we especially investigated the relationship between temperature response of the printing paper when the paper was heated by the thermal heads and thermophysical properties using experiment and 3-dimentional thermal conduction analysis. In this report, we especially evaluated a level of the effects of a thermal conduction process around the thermal head on the transient temperature response of the printing paper. The generated heat from the dot heater conducts to the platen roller through the paper as shown in Fig. 2. Therefore, thermophysical properties of the paper, thickness of the paper, the conduction thermal resistance of the platen roller and the contact resistance affect temperature rise of the paper respectively. In this paper, we especially evaluated the level of the effects of the thermophysical properties on the transient temperature response of the paper while changing the thickness of the paper and the level of the conduction to the platen roller. The 3-dimentional transient thermal conduction analysis in the paper was performed in order to observe transient temperature response of the paper. Through the analysis, we evaluated the relationship among these factors from the viewpoint of temperature rise of the paper quantitatively.

Analytical Model

Figure 3 shows the image of the analytical model for doing three-dimensional thermal conduction analysis. The structure of the proposed analytical model was based on our previous model [6]. Flow Designer version 11 made by Advanced Knowledge Laboratory Inc., which is the commercial CAE solution for flow and heat transfer analysis, was used. The model was composed of the paper, a dot heater and the boundaries. The footprint area of the paper was 1.0 × 1.0 mm^2. The footprint area of the dot heater was 0.125 mm × 0.125 mm. The dot heater was represented by the boundary that 10^{-3} W of the heat was dissipated.

The thickness of the paper was 1 mm and 0.05 mm. 1 mm thick paper was prepared in order to evaluate heat dissipation into the paper under an isotropic thermal dissipation. 0.05 mm thick paper simulated the actual thickness of the paper.

The top wall generally contacts the platen roller. The heat dissipation to the platen roller was represented as the heat transfer boundary using heat transfer coefficient. In this paper, two boundary conditions were prepared. Firstly, the adiabatic boundary was prepared on the top wall. Secondly, the constant heat transfer coefficient h boundary of 30 W/(m^2·K) was applied to the top wall surface. The constant heat transfer coefficient h boundary simulated the heat dissipation from the paper to the platen roller. The number of the mesh was 300,000 in the case of 1 mm thick and 44,200 in the case of 0.05 mm thick. Here, in our present investigation, we neglected contact thermal resistance between the paper and the heater element and between the paper and the platen roller.

In order to evaluate temperature response of the paper, transient thermal conduction analysis was performed. Temperature response of the heating point on the paper after 1 second from the start of the heating was evaluated.

Table 1 is the analytical condition of the thermophysical properties of the paper. Thermophysical properties was changed based on the measurement result [5]. Heat capacity C and thermal diffusivity α were calculated by using the following formulas.

$$C = \rho c_p b l t \qquad (1)$$

$$\alpha = \frac{\lambda}{\rho c_p} \qquad (2)$$

where b [m] is width of the paper and l [m] is length of the paper.

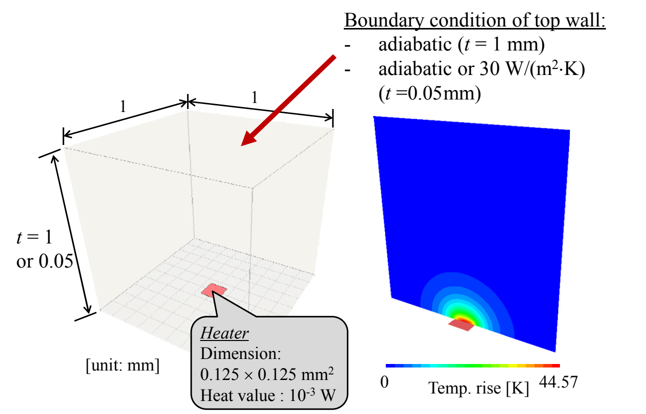

Figure 3. Schematic of analytical model (left) and example of temperature distribution after 1 second from the start of the heating in the case of t = 1 mm, ρ = 1200 kg/m^3, c_p = 1600 J/(kg·K) and λ = 0.08 W/(m·K)

Table 1 : Condition of thermophysical papers

Thermophysical properties	Conditions
Density ρ [kg/m^3]	900 – 1200
Specific heat c_p [J/(kg·K)]	1200 – 1600
Thermal conductivity λ [W/(m·K)]	0.06 – 0.08
Heat capacity C [$\times 10^{-3}$ J/K]	1.08 – 1.92
Thermal diffusivity α [$\times 10^{-8}$ m^2/s]	4.12 – 5.56

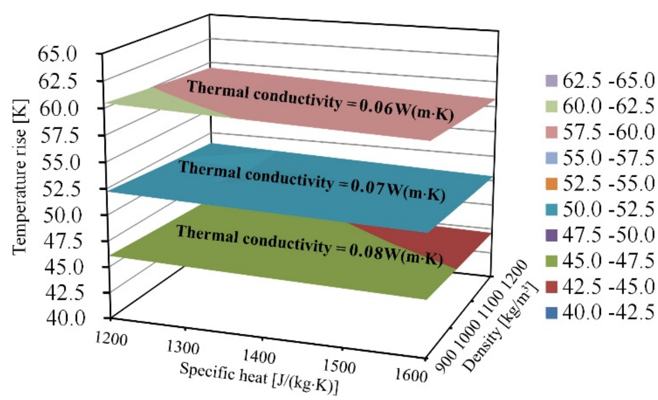

Figure 4. Relationship between thermophysical properties and transient temperature rise after 1 second from the start of the heating [6]

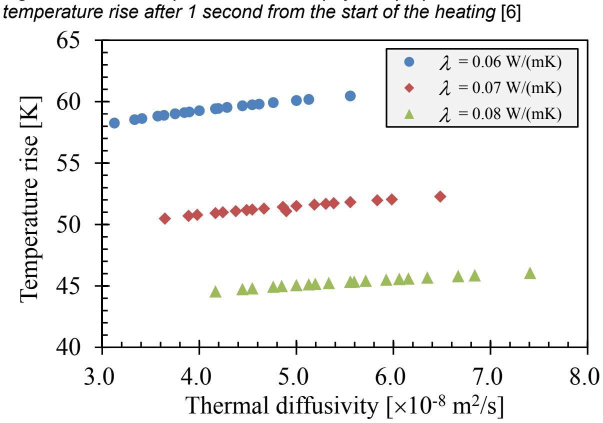

Figure 5. Relationship between thermal diffusivity and transient temperature rise after 1 second from the start of the heating [6]

Analytical Results and Discussion

Temperature and Thermophysical Properties [6]

To begin with, the previous results about the relationship between thermophysical properties and transient temperature rise when the paper thickness was 1 mm will be confirmed. Figure 4 shows the relationship between the temperature rise after 1 second from the start of the heating and the thermophysical properties. The transient temperature at the heating point of the paper is dependent on the thermophysical properties. Especially, thermal conductivity of the paper affects temperature rise of the paper significantly against the specific heat and the density.

In addition, Fig. 5 shows the relationship between the thermal diffusivity and the temperature rise. Temperature rise changes dependent on the thermal diffusivity. When the thermal diffusivity increases, the level of the temperature rise slightly increases. However, against the effect of the heat capacity and the thermal diffusivity, the effect of the thermal conductivity on the temperature rise becomes dominant. Even if the density or the specific heat is changed, if the thermal conductivity is same, the difference of the transient temperature rise of the paper becomes small. However, if the thermal conductivity is changed, the level of the temperature rise is significantly changed.

Effects of Thickness of the Paper

Next, we will investigate the effects of the conduction process on the temperature response of the paper. Especially, the effects of the paper thickness and the heat conduction to the platen roller were evaluated quantitatively.

Firstly, the effects of the paper thickness will be evaluated. Figure 7 and Table 2 shows the relationship between the temperature rise of the paper and thermal diffusivity when the thickness of the paper was changed. Here, in Fig. 7 and Table 2, the boundary on the top wall was not changed. We can see that the temperature rise of the thinner paper becomes higher than the thicker paper. In addition, in the case of the 1 mm thick paper, the change of the temperature rise by the change of the thermal diffusivity was very small. However, in the case of the 0.5 mm thick paper, the level of the effects of the thermal diffusivity also becomes higher: according to the increase of the thermal diffusivity, temperature rise becomes higher. Therefore, we can conclude that the paper thickness affects temperature response of the paper. In addition, when the paper thickness becomes thinner, the effects of the thermal diffusivity of the paper on the temperature response becomes higher.

Effects of Conduction to the Platen Roller

Secondly, the effects of thermal conduction to the platen roller will be evaluated. Figure 8 and Table 3 shows the relationship between thermal diffusivity and the temperature rise after 1 second from the start of the heating when the boundary on the top wall of the paper was changed. In this section, the thickness of the paper was not changed: 0.05 mm thick paper was investigated.

In the range of this paper, against the effects of the paper thickness on the temperature rise, the effect of the existence of the thermal conduction to the platen roller on the temperature rise may be relatively small. In addition, even if the top wall boundary was changed, the level of the effect of the thermal diffusivity on the temperature rise was small. Therefore we can say that the effect of

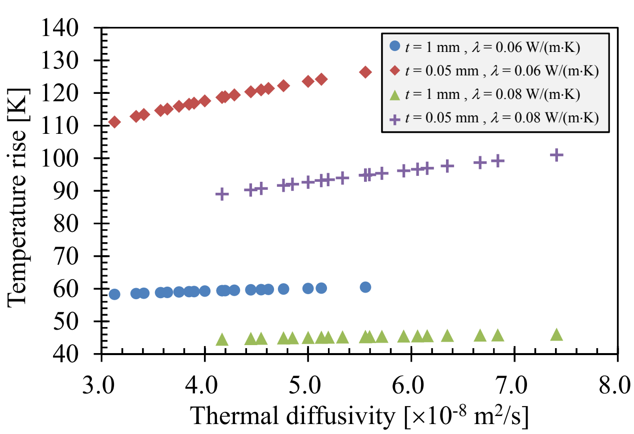

Figure 7. Relationship between thermal diffusivity and transient temperature rise after 1 second from the start of the heating when the thickness of the paper was changed (the boundary on the top wall was not changed)

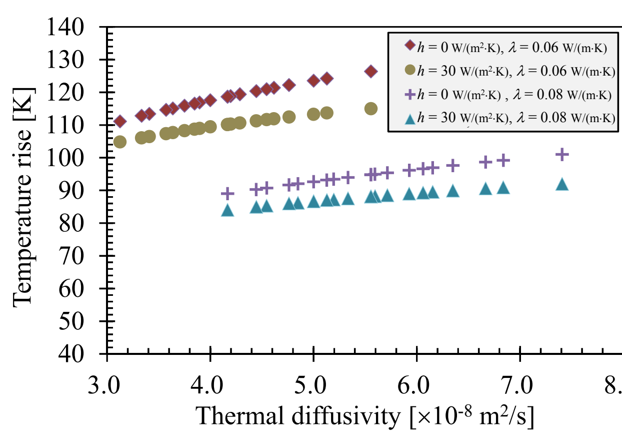

Figure 8. Relationship between thermal diffusivity and transient temperature rise after 1 second from the start of the heating when the boundary on the top wall of the paper was changed (thickness of the paper = 0.05 mm)

Table 2 : Change of temperature rise which α and λ was changed respectively when the adiabatic condition is applied on the top wall and *t* was changed

Thickness	t = 1 mm			t = 0.05 mm		
α [$\times 10^{-8}$ m^2/s]	4.2	4.8	5.2	4.2	4.8	5.2
λ = 0.06 W/(m·K)	59.4	59.9	60.2	118.9	122.2	124.2
λ = 0.07 W/(m·K)	51.0	51.3	51.6	102.1	104.3	106.7
λ = 0.08 W/(m·K)	44.6	45.0	45.2	89.0	92.0	93.4

Table 3 : Change of temperature rise which α and λ was changed respectively when *t* = 0.05 mm and the adiabatic condition was changed

Thickness	h = 0 W/(m^2·K)			h = 30 W/(m^2·K)		
α [$\times 10^{-8}$ m^2/s]	4.2	4.8	5.2	4.2	4.8	5.2
λ = 0.06 W/(m·K)	118.9	122.2	124.2	110.3	112.4	113.7
λ = 0.07 W/(m·K)	102.1	104.3	106.7	95.6	97.1	98.8
λ = 0.08 W/(m·K)	89.0	92.0	93.4	84.1	86.3	87.6

thermal conduction to the platen roller may be relatively smaller than the effects of the paper thickness or thermal conductivity. Actually, the printing process of the DTP is fast. Therefore, the heat leak from the reverse side of the paper to the platen roller may be not a severe problem. However, if the level of the thermal conduction to the platen roller becomes higher, there is a possibility that temperature rise of the paper is inhibited. The detailed investigation about the heat leak to the platen roller should be done as our future research.

Summaries

In this paper, we evaluated the level of the effects of the thermophysical properties on the transient temperature response of the paper while changing the thickness of the paper and the level of the conduction to the platen roller quantitatively. The 3-dimentional transient thermal conduction analysis around the paper was performed and the transient temperature response of the paper was performed. Through the analytical results, we obtained the undermentioned summaries.

In addition to thermal conductivity, the paper thickness affects temperature response of the paper in DTP process. The transient temperature rise of the thinner paper is faster than the thicker paper. In addition, the effects of the thermal diffusivity of the paper on the temperature response becomes higher when the paper thickness becomes thinner. On the other hand, the existence of the thermal conduction to the platen roller may not affect paper's temperature rise significantly. Therefore, in actual DTP process, accurate information about thermal conductivity, paper thickness and thermal diffusivity of the printing paper may be important in order to predict accurate estimation of paper's temperature rise.

However, in our present report, the parameter survey of each factor was not enough. In addition, the physical reason of the present result was not clear. In addition, the existence of the contact resistance also affects temperature response [5]. The additional investigation should be performed and accurate prediction model which can be available for predicting temperature rise of the paper in DTP process by using thermophysical properties should be developed.

Acknowledgement

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Author Biography

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