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Basic Study on Evaluation Method of Thermal Conduction through Printing Papers using 1-Dimensional Thermal Conductivity Measurement

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Abstract

This study targets to develop a 1-dimensional evaluation method of thermal conduction process around printing papers in DTP (Direct Thermal Printing) process. Our special attention was paid to investigate an evaluation method of thermal conductivity and contact thermal resistance of the printing papers. The evaluation of thermal conductivity of the printing papers is generally difficult because thermal conductivity of the papers is small like insulation. In addition, contact thermal resistance between the thermal head and the papers cannot be measured directly. Therefore, in this report, the clarification of the level of the thermal conductivity and the contact thermal resistance were targeted by using 1-dimensional thermal conductivity measurement system.

From the measurement of the equivalent thermal conductivity, the level of the difference of the thermal conductivity and the contact resistance of the paper was investigated. In addition, the optimum pressing pressure of the platen roller in order to minimize thermal contact resistance is clarified.

Introduction

Direct Thermal Printers (DTP) prints images by selectively heating thermal papers by using a thermal head that lots of dot heaters are mounted (Fig. 1). In recent years, a great demand of DTP to portable Point-Of-Sale (POS) terminals is surging. 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 print images by using only thermal papers and input heat from the thermal head. Therefore, DTP has been widely used for the printer of the POS terminals.

Several researchers have been investigated about printing technologies and thermal design of DTP [2] – [5]. However, in order to prolong battery life of POS terminals, more decrease of a power consumption is strongly needed while improving printing quality and doing color printing. The printing quality and the power consumption of the DTP are dependent on thermal conduction between the thermal head and the platen roller through the printing paper. Therefore, an additional investigation about thermal conduction of DTP process may be effective for optimizing the structure of the DTP and the power consumption of the thermal head. Moreover, a shortening of a design period of productions are required in order to sustain and raise competitiveness of the products. A design framework called "1DCAE" has been brought to designer's attention regardless of the branch of engineering [6]. Thermal resistance network analysis [2] has also been growing as a "1DCAE-based" rapid and accurate heat transfer prediction tool for thermal design of electronic equipment. An application of the methodology of the 1DCAE-based thermal design scheme to DTP may be effective to shorten production period and to optimize the design of the thermal head. However, in order to achieve the development of the faster and easy thermal design scheme for the DTP, more basic information about thermal conduction phenomena around the thermal head and the printing papers should be collected.

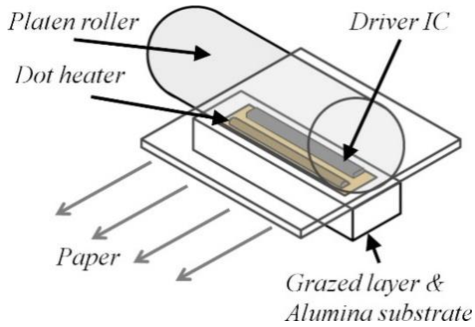

Figure 1. *Schematic of Direct Thermal Printing Process* [1]

From these backgrounds, our study aims to investigate a relationship between printing process of DTP and thermal conduction phenomena in order to develop easy and accurate thermal design method for DTP [1] [7]. 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 3-dimensional thermal conduction analysis. We have reported that thermal conductivity of the printing papers strongly affects transient temperature response when heating the papers. In order to design the optimum heating process by the thermal head, an accurate evaluation of thermal conductivity becomes important. However, an evaluation of thermal conductivity of the printing papers is generally difficult because thermal conductivity of the papers is small like insulation. In addition, contact thermal resistance between the thermal head and the papers cannot be measured directly. Therefore, an evaluation method of a level of thermal conductivity of the papers and the contact resistance should be investigated.

Therefore, in this report, the clarification of the level of the thermal conductivity and the contact thermal resistance were targeted by using 1-dimensional thermal conductivity measurement system [7] [8]. Through the measurement, the level of the difference of the thermal conductivity and the contact resistance of the paper was clarified. In addition, the optimum pressing pressure of the platen roller in order to minimize contact thermal resistance was investigated.

Measurement System

Figure 2 shows the schematic of the 1-dimensional thermal conduction measurement system. The measurement system was developed by Tomimura et al. [8]. The test section consists of a test paper, two brass rods of 40 mm in diameter and length of 45 mm, a film heater, a cooling block and an acrylic block as shown in Fig. 2. The test paper was mounted between two brass rods. By applying voltage to the film heater by using the power supply, the heat was generated. In addition, the cooling water was applied to the cooling block by using the thermostatic bath. By using the heater and the cooling block, temperature difference between the top of the upper brass rod and the bottom of the lower brass rod is caused and the heat flow is generated between the heater and the cooling block through the rods and the test paper. In order to evaluate temperature distribution in the rods, 8 T-type sheathed thermocouples were prepared and temperature data was collected by using a data logger. The thermocouples were inserted into the holes of 0.5 mm in diameter and depth of 5 mm in the rods. The test section

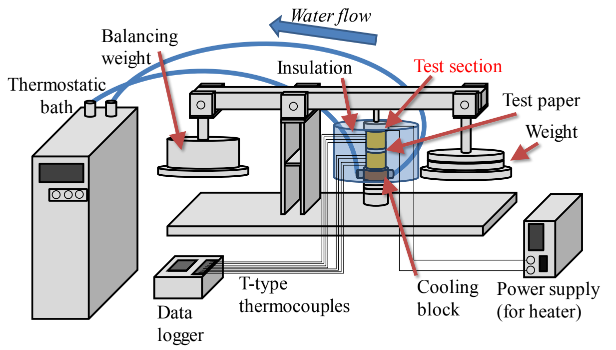

***Figure 2.** Schematic of 1-dimensional thermal conduction measurement system*

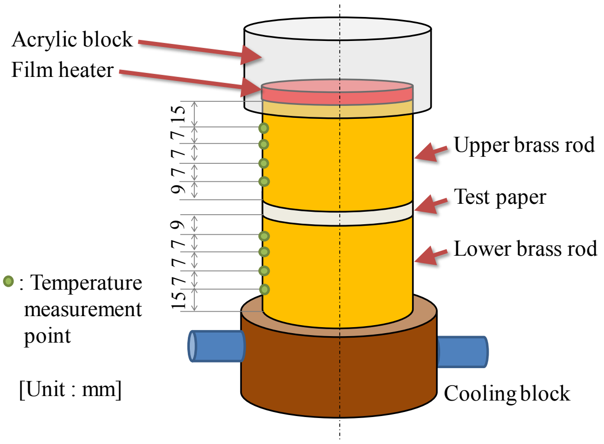

***Figure 3.** Details of test section and measurement point of temperature*

was covered with polystyrene foam for insulating heat leak from the surface of the rods. The load was applied to the test section by using the principle of leverage. The pressing pressure to the upper rod was changed by changing the weight. The pressing pressure of the weight simulates a contact pressure of a platen roller. The balancing weight was mounted at the opposite end of the beam in order to obtain the no-loaded condition.

Evaluation Method

Figure 4 shows an image of temperature distribution in the rods. As shown in Fig. 4, we can obtain one-dimensional temperature field. When the test section reach steady state, temperature difference between the lower surface of the upper rod (top surface of the test paper) and the upper surface of the lower rod $\Delta T_p = T_{p1} - T_{p2}$ causes. Thermal resistance through the test paper R can be calculated by using the following formula:

$$R = \frac{\Delta T_p}{Q_p} \quad \text{[W]} \tag{1}$$

Where Q_p is the heat flow through the test paper. Here, R includes thermal conduction resistance in the paper and contact resistance on the paper surfaces. In this paper, we evaluated thermal conductivity as an equivalent value which includes both thermal conduction resistance and the contact resistance. The equivalent thermal conductivity was evaluated from thermal resistance as shown in Eq. (1).

$$\lambda_p = \frac{t_p}{RA} \quad \text{[W/(m·K)]} \tag{2}$$

Where λ_p [W/(m·K)] is the equivalent thermal conductivity of the test paper, t_p [m] is the thickness of the paper and A [m^2] is the cross-sectional area of the paper.

Here, the heat flow through the rod Q was evaluated by using the temperature change in the rods and the following Fourier's law:

$$Q = -\lambda_b A\left(\frac{dT}{dx}\right) \quad \text{[W]} \tag{3}$$

Where λ_b [W/(m·K)] is thermal conductivity of the brass and dT/dx [K/m] is the temperature gradient in the rods. λ_p was preliminary obtained experimentally using the same rod that the length was 90 mm. By using temperature difference between adjacent thermocouples and the distance between the thermocouples. By using Eq. (1), the heat flow in each rod can be calculated individually. In this paper, the heat flow through

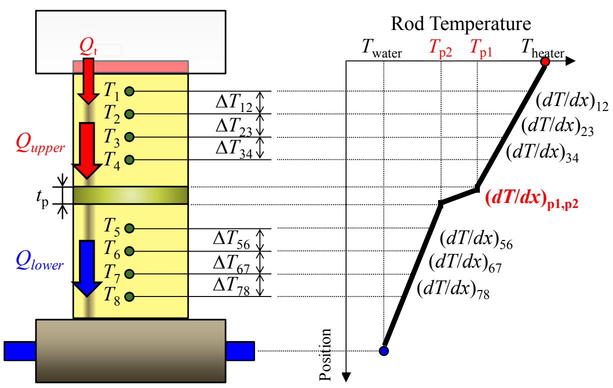

***Figure 4.** Evaluation method of temperature gradient in test section*

the printing paper was evaluated by the average of the heat flow in the upper rod and the heat flow in the lower rod.

$$Q_p = \frac{Q_{\text{upper}} + Q_{\text{lower}}}{2} \qquad [\text{W}] \qquad (4)$$

Where Q_{upper} [W] is the estimated heat flow from temperature distribution in the upper rod and Q_{lower} [W] is the estimated heat flow from temperature distribution in the lower rod.

Test Papers

Table 1 shows the details of the test papers. In order to compare the difference of the thermophysical properties from the type of the papers, five types of papers were evaluated. In the experiment, the test paper was cut in a circular piece of 40 mm in diameter and was held between the brass rods.

In order to evaluate a reliability of the measurement system, thermal conductivity of the acrylic test piece (40 mm in diameter, thermal conductivity of 0.21 W/(m·K)) was also measured as the preliminary experiment.

Results and Discussions

Firstly, we will confirm the measurement result of thermal conductivity of the acrylic test piece. Figure 5 shows the measurement result of thermal conductivity of the acrylic test piece. Figure 5 also denotes the relationship between thermal conductivity and the thickness of the acrylic test piece. The measurement results and the nominal value were in good agreement regardless of the thickness of the acrylic test piece. From these results, we confirmed that the thermal conductivity of the acrylic test plate can be measured correctly.

Secondly, the result of the thermal conductivity measurement of each test paper will be discussed. Figure 6 shows the measurement result of the equivalent thermal conductivity of the test papers. We confirmed that the equivalent thermal conductivity is dependent on the type of the test paper. This difference is caused by the structure of the test paper, that is an orientation of paper fibres, fibre density and the type of the coating on the paper. From Fig. 6, the simple structure paper such as thermal paper, xerographic paper and high grade paper show relatively lower thermal conductivity. In this case, the level of the value of the thermal conductivity was slightly similar to the nominal value of thermal conductivity of the paper (0.06 W(m·K)) [10]. On the other hand, the papers with the coating layer such as thermal transfer printer and inkjet paper show relatively higher thermal conductivity. Thermal conductivity of

Table 1. *List of test paper*

Type of paper	Cross section	Thickness [mm]
Thermal paper		0.055
Xerographic paper		0.065
High grade paper		0.100
Thermal transfer paper		0.200
Inkjet paper		0.300

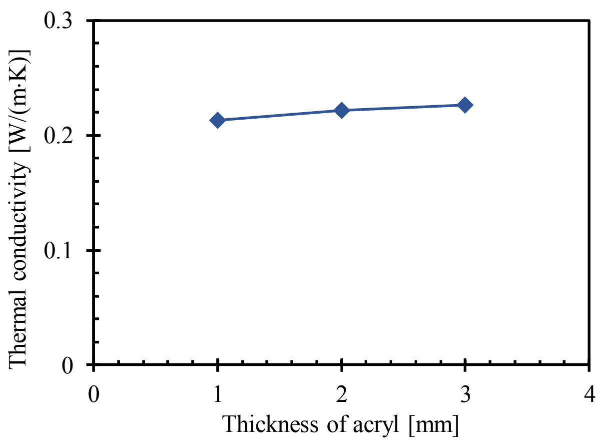

Figure 5. *Relationship between measurement result of thermal conductivity of acrylic test piece and thickness.*

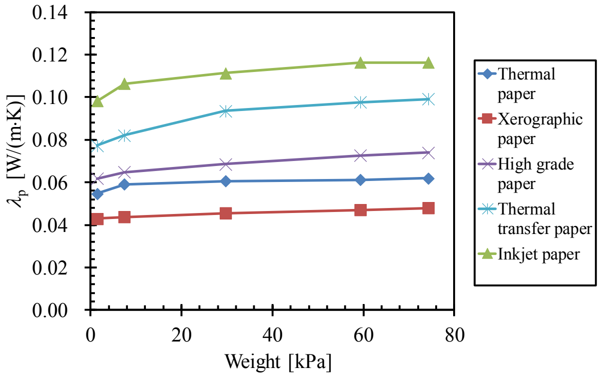

Figure 6. *Relationship between thermal conductivity of paper and pressing pressure*

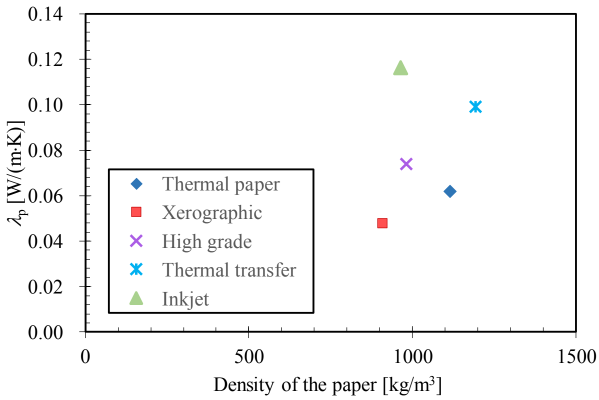

Figure 7. *Relationship between thermal conductivity of paper and density*

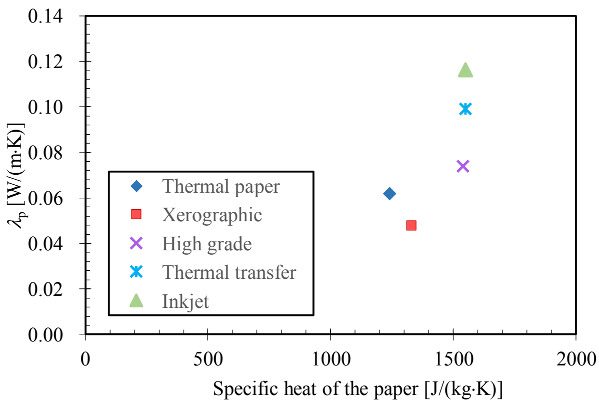

Figure 8. *Relationship between thermal conductivity of paper and specific heat*

coating materials (such as rasin) may be higher than the paper. Hence the equivalent thermal conductivity of these papers may become higher.

Here, Fig. 7 shows the relationship between the density of the paper and the thermal conductivity. Figure 8 denotes the relationship between the specific heat of the paper and the thermal conductivity individually. From these graphs, the causal relationship between other thermophysical properties and measured thermal conductivity was not actually proven. At present, the detailed thermophysical properties of additional materials expect for the paper are unknown. The further investigation about an evaluation of the effects of additional materials to thermophysical properties of the papers should be needed.

On the other hand, Fig. 6 also shows the relationship between the equivalent thermal conductivity and the pressing pressure. We can confirm that the pressing pressure of the weight also affects the equivalent thermal conductivity. When the pressing pressure increases, the test paper adheres well to the weight. Hence contact thermal resistance decreases with increasing the pressure. However, when the pressure value becomes 60 kPa or higher, the level of the contact resistance is not changed regardless of the type of the paper. We concluded that there is an optimum pressing pressure that can minimize the contact thermal resistance. In the range of our experiment, we conclude that the pressing pressure that the platen roller pressurizes the paper should be higher than 60 kPa.

Summaries

In this research, we tried to evaluate the level of the thermal conductivity and the contact thermal resistance through the 1-dimensional thermal conductivity measurement. We especially evaluated the equivalent thermal conductivity which includes both thermal conduction resistance and the contact resistance. The optimum pressing pressure of the platen roller was also investigated. In the range of our present investigation, we obtained undermentioned information.

The value of the equivalent thermal conductivity is dependent on the type of the printing paper. The equivalent thermal conductivity of simple structure papers that don't have the coated layer has similar to the nominal value of the simple

The equivalent thermal conductivity is dependent on the pressing pressure. However, there is an optimum pressing pressure that can minimize the contact thermal resistance. In the range of our experiment, the optimum pressing pressure that the platen roller pressurizes the paper was 60 kPa.

In our future works, an increase of the reliability of the thermal conduction measurement should be discussed. In addition, a concrete method of 1D-based thermal design for DTP process will be prepared by using our previous results.

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