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Basic Study on Effects of Water Content on Printing Paper on Equivalent Thermal Conductivity

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Abstract

This paper describes a relationship between a water content of printing paper and an equivalent thermal conductivity that affects to printing quality of printers using the heat such as laser printers and direct thermal printers. Our study targets to describe the relationship between the water content and the thermal conduction in the printing process. Especially in this report, we firstly investigated a relationship between the humidity around the paper and the change of the water content of the thermal paper. The dried thermal paper was mounted in the constant temperature and humidity chamber and the time history of the change of the paper weight was measured by using the precision balance. It is found that the water content of the thermal paper is dependent on the humidity. However, even if the humidity around the paper is changed, the water content of the paper is rapidly saturated according to the humidity. Therefore, from the viewpoint of the thermal design of the printing process, the transient change of the water content of the paper may not become important against the value of the humidity itself. In addition, the relationship between the water content of the paper and the thermal conductivity was investigated through a combination of the 1-dimensional thermal conduction experiment in the constant temperature and humidity chamber with the thermal network analysis.

Introduction

Thermal conduction through printing papers is a key physical phenomenon of several printing processes using heat such as direct thermal printers (DTP) and laser printers. The printing papers are generally made of lots of pulp fibres and the papers have high hygroscopicity. There is a difference of thermophysical properties between the pulp fibres and the water. The level of a moisture absorption affects thermal conduction around the papers during the printing process such as a curling phenomenon of the paper and the bleeding of the ink. An environmental condition of the printers varies according to users. Therefore, in order to improve the printing quality of the printers regardless of the environmental condition, an additional investigation about the relationship between the environmental condition of the printers and the printing quality should be needed. From the viewpoint of heat transfer phenomena in the printers using heat, the water content of the paper affects to thermal conduction in the printing paper and this causes the change of the printing quality. A clarification of the relationship between the water content and the thermal conduction around the paper becomes important in order to optimize the design parameter of the printers.

We have already investigated about an evaluation method of thermal conduction around the papers using the 1-dimensional thermal conduction measurement [1] and transient thermal network analysis [2]. The effects of thermophysical properties and contact thermal resistance on the transient temperature response of the papers have been clarified. On the other hand, humidity around the printers is dependent on the environment conditions such as weather and regions. Generally, the paper has hygroscopicity and the water content of the paper may affect to the thermal conduction process. In order to clarify the relationship between the water content and the thermal conduction around the paper quantitatively and improve the thermal management in the printers, a development of a detailed database about the effects of the water content of the paper on the thermal conduction should be advanced.

Against these backgrounds, this study tried to investigate an effect of the water content of the printing paper on the thermal conduction in the printing process through both experiment and numerical analysis. Firstly, the relationship between the water content of the paper and the humidity was investigated. Secondly, the relationship between the water content and equivalent thermal conductivity was evaluated by the combination of the 1-dimensional thermal conduction experiment and the thermal network analysis.

Water Content Measurement

Experimental Systems:

Figure 1 shows the experimental apparatus of the measurement of the water content of the paper. A constant temperature and humidity chamber was used. The test papers were mounted in the chamber and the transient change of the weight of the paper by the water content was measured by the precision balance. The measurement condition and the test papers were chosen as shown in Table 1.

Evaluation Method of Water Content:

Water content was evaluated by the following formula:

$$w_{H_2O} = \frac{m_0 - m_1}{m_0} \times 100 \quad [\%] \tag{1}$$

where w_{H2O} [%] is the water content of the test paper defined by JIS P 8127 (3), m_0 [g] : the weight of the wetted test paper by the humidity in the chamber, m_1 [g]: the weight of the dried test paper.

Measurement Result:

Figures 2 and 3 show the transient change of the water content of each test paper. Figure 2 is the result in the case of 80 % of the humidity and Fig. 3 is the result in the case of 95 % of the humidity. The water content of the paper was dependent on the type of the test paper. Here, the change of the water content was changed according to the time. However, the water content saturated over time. From Fig. 3, the water content was not changed 180 seconds later from the start of the experiment. Therefore, we conclude that the water content of the paper is dependent on the humidity. However, from the transient change of the experimental results, the water content of the paper is rapidly saturated. Therefore, when the humidity of the surrounding condition of the printers can be measured, the level of the water content may be estimated. On the other hand, in the range of the present research, the effect of the surrounding temperature on the water content is smaller than the effect of the humidity.

Thermal Conductivity Measurement

Experimental Systems:

In order to measure the relationship between the humidity and the thermal conductivity, the 1-dimensional thermal conductivity measurement system(4) that can be used in the constant temperature and humidity chamber as shown in Fig. 4 (a) was prepared. The test paper was mounted between the upper unit and the lower unit. Each unit is composed of a cooling block, a SUS304 metal block, the test paper and a heater. The unit has symmetrical structure in the horizontal direction of the heater. The generated heat from the heater flows to each cooling unit through the test paper. Therefore, 1-dimensional thermal conduction is caused through the paper in each unit separately.

Evaluation Method of Thermal Conductivity:

As shown in Fig. 4 (b), due to the test papers, temperature difference causes between each surface of the paper. Therefore, equivalent thermal conductivity λ_p [W/(m·K)] can be calculated using the following formula.

$$\lambda_p = Q_p \times \frac{l_p}{A \Delta T_p} \quad \text{[W/(m·K)]} \qquad (2)$$

Where Q_p [W] is the heat through the paper, l_p [m] is the thickness of the paper, A [m^2] is the heat transfer area and ΔT_p is the temperature difference between the papers. By this formula, we can measure equivalent thermal conductivity of the paper. However, when the level of thermal conductivity of test material is small, generally heat dissipation from the experimental apparatus to the surrounding environment is caused. Therefore, in this research, the net heat flow through the paper was predicted through 1D-CAE simulation using Modelica (5) and the corrected heat flow was uses as Q_p.

$$Q_P = Q_{input} - Q_{dissipation} \quad \text{[W]} \qquad (3)$$

Where Q_{input} [W] is the input heat from the heater and $Q_{dissipation}$ [W] is the predicted heat leakage from the test section surface to the surrounding environment.

Table 2 shows the experimental condition. In this paper, the thermal paper was choses as the test paper. The relationship between humidity and thermal conductivity was evaluated using steady method.

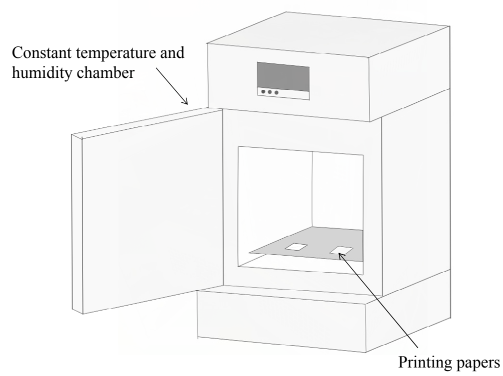


Figure 1. *Schematic of water content measurement.*

Table 1 Conditions of water content measurement

	Moisture grant	Drying
Paper length [mm]	50 × 50	
Temperature [ºC]	20, 40	105
Humidity [%]	80, 95	30
Time [s]	1800, 3600, 5400, 7200	1800
Paper Type	Thermal paper, Recycle paper, Xerographic paper, High-grade paper, Thermal transfer paper, Inkjet paper	

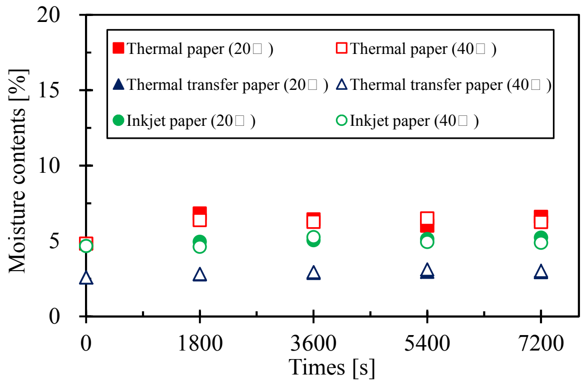


Figure 2. *Transient relationship between water content and time in the case of 80 % of humidity.*

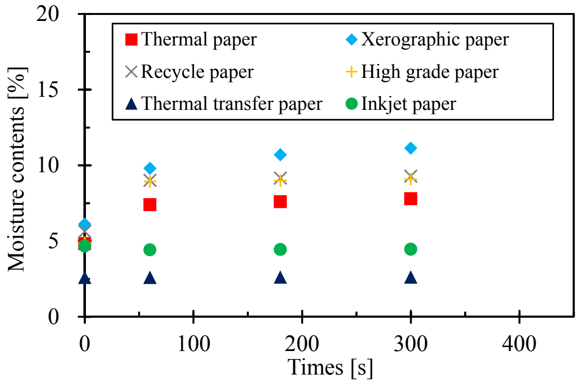
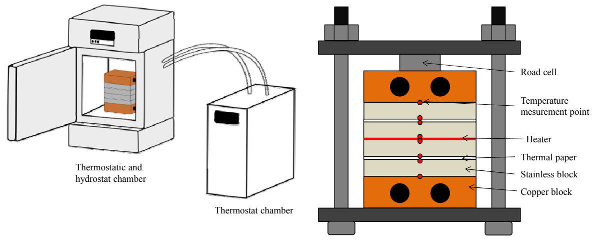
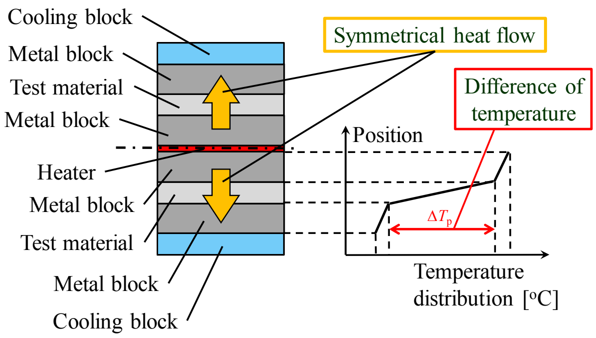


Figure 3. *Transient relationship between water content and time in the case of 40 % of surrounding temperature and 95 % of humidity.*



(a) Schematic of thermal conductivity measurement apparatus



(b) Evaluation method of thermal conductivity

Figure 4. *Measurement method thermal conductivity.*

Table 2 Measurement conditions of thermal conductivity

Applied power to the heater [W]	19.4
Number of paper sheets [-]	3, 5
Temperature environment [°C]	20, 40
Humidity environment [%]	40, 60,80,95
Surface area [m^2]	2.5×10^{-3} (0.05m×0.05m)
Mesurement time [s]	1800

Measurement Result:

Figure 5 shows the relationship between humidity and equivalent thermal conductivity. Here, "5 sheets" is the result when 5 thermal papers were sandwiched and "3 sheets" is the result when 3 thermal papers were sandwiched. We can confirm that the equivalent thermal conductivity was dependent on the humidity. According to the increase of the humidity, equivalent thermal conductivity becomes higher. This is because the thermal conductivity of the water is higher than the paper itself. On the other hand, the equivalent thermal conductivity was also changed by the environment temperature. About the water content, in the range of our research, the effect of the humidity on the water content becomes small. This may be caused by the increase of thermal conductivity of the paper itself by increase of temperature. An additional investigation about the reason of the increase of the equivalent thermal conductivity will be performed in our future research.

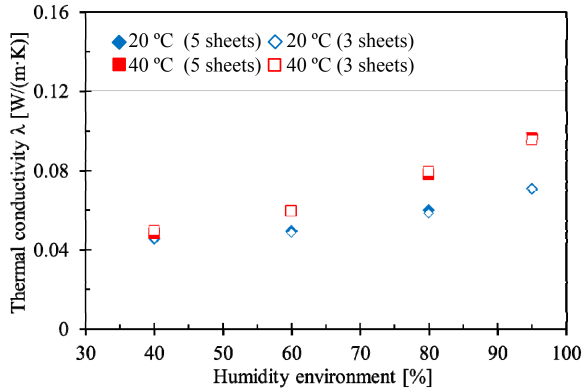


Figure 5. *Equivalent thermal conductivity of thermal paper from combination of experiment and analysis*

Summaries

In order to improve the design process of each printing machines, the basic research of the thermophysical properties of the printing papers was performed. In this paper, especially we targeted to investigate the effects of the humidity on the equivalent thermal conductivity through 1-dimensional thermal conductivity measurement with 1D-CAE simulation by Modelica. The relationship between the humidity and the water content was also discussed. Through the research, we found that the equivalent thermal conductivity of the paper was affected by the humidity of environmental condition. On the other hand, surrounding temperature also affects to the equivalent thermal conductivity.

The change of the thermal conductivity may be caused by increase of the water contents by the humidity. Regardless of the type of the papers, the water content is dependent on the humidity. However, the change of the water content by the time becomes small. Therefore, when we obtain information of surrounding condition of printers, there is the possibility that the prediction of water content of the paper will become easily and we can also predict the equivalent thermal conductivity. The systematic method of thermal design of printing process including above information will be discussed in our near future research.

References

[1] T. Fukue, H. Terao, K. Hirose, Y. Sasaki, T. Wauke, H. Hoshino, T. Tomimura and Y. Koito, "Basic Study on Evaluation Method of Thermal Conduction through Printing Papers using 1-Dimensional Thermal Conductivity Measurement", Proceedings of the NIP32 Conference. (2016).

[2] T. Fukue, H. Terao, K. Hirose, T. Wauke, H. Hoshino, R. Ito, and F. Nakagawa, "Investigation of Transient Temperature Response of Papers in a Thermal Transfer Printer", Proceedings of the NIP29. (2013).

[3] JIS P 8127, Paper and board-Determination of moisture content of a lot-Oven-drying method (2010).

[4] J. Hatakeyama, K. Hirose, M. Uchidate and T. Fukue, "Parameter Research of Thermal Conductivity Measurement by Steady Temperature Prediction Method through 1D Simulation", Proceedings of the 28th International Symposium on Transport Phenomena (2017).

[5] Fukue, T. and Ohtomi, K., "Heat Transfer Modeling of Tea Time using OpenModelica (in Japanese)", Presentation material, OpenCAE Symposium Japan (2017).