Considerations on Energy Supply of Heat and Pressing Work for Toner Fusing

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Abstract

In 2000, the author and his team reported on the effects of the heat supply and the nip pressure from an aspect on energy supply to toner in Japan. [1] They found in typical roll fusers that influence of nip width enhancement, only by hardness reduction for back-up roll elastic layer without increasing pressing load, to fixing strength is very little. It provided that fixing strength contour in coordinates of heat supply and pressure. As a result, the contour diagram could derive design concepts and procedures for basic specifications in roll fusers.

The prior study described above contains some outstanding issues, especially for the mechanism solving, which should be examined. The thermal energy represented by the heat supply was discussed in it. However, absorbed or latent heat should be examined and aspects from rheology should also be provided, for comparing pressing work. In the present report, the prior study is reviewed and further considerations are provided for the issues.

Introduction

Fusing is a process of energy supply by heat and pressing work in nip region. To know quantitative effects of them is quite important for designing electrophotographic fusers. To clarify its mechanism is also very important for making progress of the fusing technology.

A few reports, which discuss toner fusing from a point of view on the energy supply, can be found, as far as the author knows. The present author reported one entitled as “Energy Analysis in an Electrophotographic Fusing Process” in 2000 published in Japan. [1] Another report, entailed as “Thermal Analysis for Electrophotographic Toner During Fusing” in 1997 published in Japan, contains toner thermal latent energy absorption property during melting. [2]

The former literature provides relationship between the heat supply and the nip pressure from an aspect on energy supply to toner. And then a heat roll fuser design procedure is led. However, physical mechanism for toner melting and fixing is not mentioned very much. Therefore, the energy level of the heat supply is too much comparing to the pressing work. This is caused from a lack of the point of view for the thermal absorption in toner because of consideration without toner melting and fixing precise physical model. Fortunately, the later literature provides thermal absorption during melting.

In this study, the former literature is reviewed and then more precise physical interpretation is provided using the result in the later literature.

Fuser System

Fuser system makes the toner fixed on a paper in an

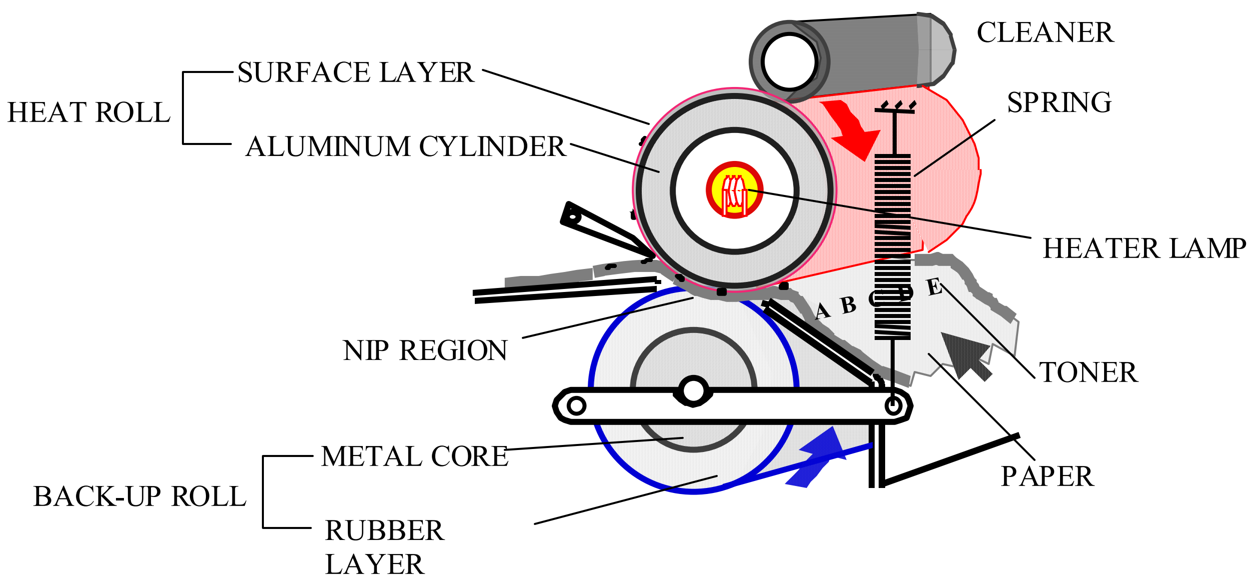


Figure 1. Heat Roll Fuser.

electrophotographic process. The most important matter in the fuser system is obtaining sufficient fixing strength. Mainly two types of fuser principals are well known. One is non-contact fusing with xenon flashlights, another is contact fusing, in which heat and pressure are supplied to the toner. The former is called flash fusing, the later is called as a heat roll fusing.

Figure 1 shows a schematic of a typical heat roll fuser, which is an example dealt with in this study. The system is mainly composed of a heat roll and a back-up roll. The heat roll has a thin surface layer made of fluoride resin on an outer surface of an aluminum cylinder for preventing toner offset. The surface layer behaves as a thermal resistance in the nip region. Therefore, the thin surface layer thickness is set around 20-40 µm. Back-up roll has a elastic layer, normally made of silicone rubber, on an outer surface of a metal core. Small amount of offset toner is generated even though the fluoride surface layer is formed on the heat roll. Therefore an offset toner cleaner is installed on the heat roll. The heat roll and the back-up roll are pressed against each other and rotated. Elastic deformation by pressing load of the back-up roll makes a nip region. Circumferential length, transit time and pressure of the nip region are called as nip width, nip period and nip pressure, each other. The nip period is normally several ms to several ten ms to obtain a sufficient thermal energy supplies to toner with high temperature as 130ºC or higher for the heat roll. The nip pressure is normally set as 5-50 N/cm^2 for applying pressing work to the toner.

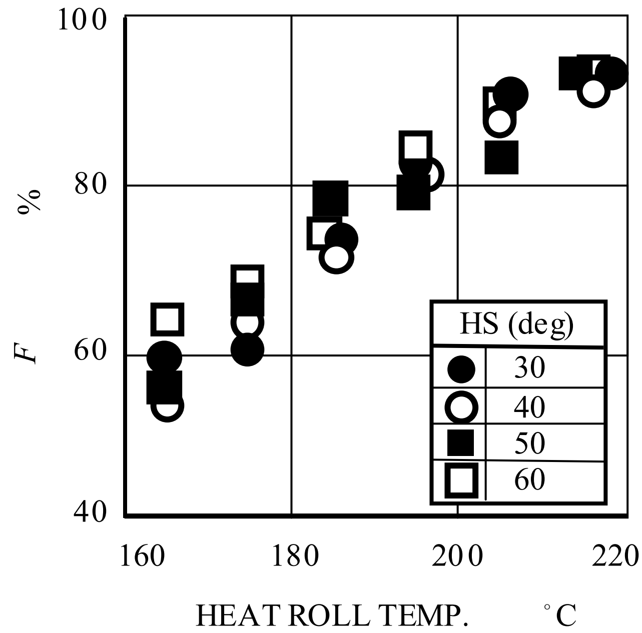


Figure 2. Fixing Strength with Rubber Hardness.

Review for the Previous Work [1]

The previous work [1] is reviewed in this section. Figure 2 shows tested relationships between fixing strength, *F*, and heat roll temperature with the back-up roll elastic layer hardness. The heat and pressure balance is changed with the elastic layer hardness. However, the fixing strength is not varied even the elastic layer hardness changed. Therefore, the total energy to the toner by heat and pressing is considered as constant.

Net heat for melting in unit area, *Q*, is shown in Eq. (1).

$$Q = k\int_0^T \dot{q}dt \qquad \text{------------------------} \qquad (1)$$

Where, heat flux to toner, the nip period, transit time after nip region inlet and converting coefficient from heat supply to net heat for melting are denoted as $\dot{q}$, *T*, *t* and *k*, each other. The heat for melting can be represented by the heat supply, *Q*/*k*, if the coefficient, *k*, is assumed as constant.

The pressing work in unit area for toner deformation, *W*, is shown in Eq.(2).

$$W = P \cdot \delta L \qquad \text{--------------------------} \qquad (2)$$

Where, toner deformation and nip pressure are denoted as δL and *P*. The pressing work can be represented by the nip pressure, *P*, since in same fixing strength level, the toner deformation, δL, is considered as constant.

Relationship between heat supply, *Q*/*k*, which represents the heat for melting, and pressing work, *P*, which represents the pressing work, is shown in Figure 3. Curves in Figure 3 satisfy the relationship shown in Figure 2, which means that the total energy of heat and pressing work is constant with changing the balance

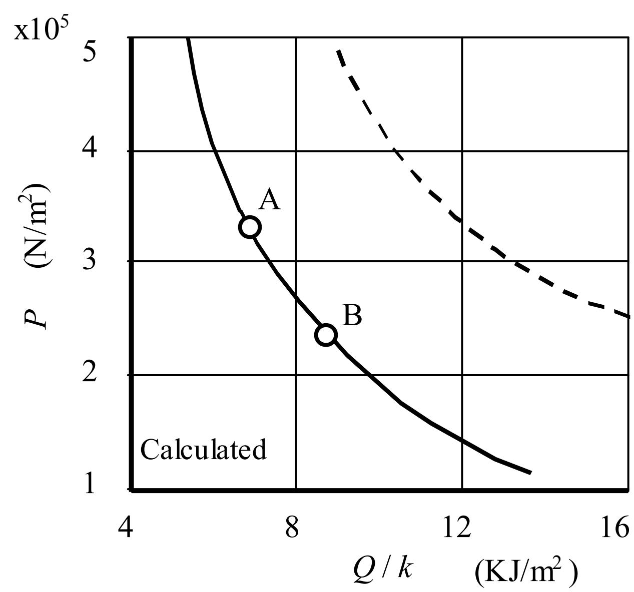


Figure3 . Contour Diagram of Fusing Energy.

between the heat and pressing work. And they are calculated from varying the elastic layer hardness only. Equal fixing strength can be obtained on each curve.

From this fixing strength contour line, some fuser specifications can be derived. Table 1 shows two examples of

Table 1 Specifications of Fuser.

	A	B
NIP WIDTH	10 mm	7 mm
NIP DURATION	14 ms	25 ms
HR/BR LOAD	3.3 N/mm	1.8 N/mm
HR/BR DIAMETER	86 mm	46mm
HR TEMP.	190℃	170℃
HR SL	t 20 µm	t 40 µm
BR HARDNESS	HS 50 DEG	30 DEG
BR RUBBER	t 10 mm	t 6 mm

HR: HEAT ROLL BR: BACK-UP ROLL
SL : SURFACE LAYER

fusers. A is for high speed fusing and B is for relatively lower speed fusing. The energy balance of A and B fusers are corresponding to point A and B in Figure 3, respectively.

Considerations on Energy Supply to Toner

For the next step to make progress from previous work [1], following problems should be examined.

1. Toner fusing is not physically modeled.
2. Converting coefficient from heat supply to net heat for toner melting, *k*, is assumed as constant. However, it is not assured and the level of *k* is not cleared. In other words, it is not clear that the energy levels comparison between the net heat for the melting and pressing work.

Providing complete solution for these problems is hard. However, considerations for them are attempted in this report.

Toner Fusing Physical Model

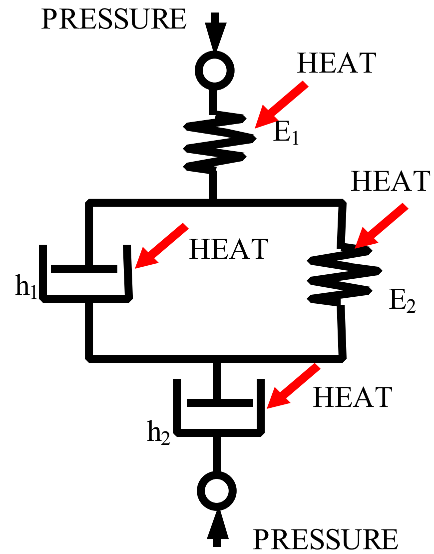
It is well known that melt toner shows viscoelastic behavior. Figure 4 shows fusing model, which is from Four-Element Model in rheology field describing viscoelastic deformation.

In this model, the heat supply affects to dash pots, which represent viscosity, and springs, which represent elasticity. This means that the heat affects toner melt properties and makes it soften. It is important that the heat is not heat supply, but absorption in toner. The problem No. 2 listed above is that the heat supply was used in evaluating thermal energy for fusing in the previous work. Evaluation of the absorbed heat and the pressing work are examined in the next section.

The pressing force is applied to top and bottom terminals. Multiplication of the force (*P* if unit area) and deformed distance (δL) is derived as pressing work.

From this model, it is clear that the fusing consists of two functions. One is property softening by the thermal absorption. If only the thermal absorption is occurred, the fusing is not completed. Another indispensable function is deformation by pressing force. The former function is called melting and the later function is called fixing in the present report.

Thus, various combinations of melting and fixing levels provide same fixing strength. In extreme example tabled in Figure 4, comparison between the heat roll and the flash fusing can be presented. For the heat roll fusing, the heat supply is small because of relatively low temperature application by heat roll, but higher



	TEMP.	PRESSURE
FLASH	HIGH	LOW
HEAT ROLL	LOW	HIGH

Figure4 . Toner Fusing Model.

pressure is applied in the nip region. On the other hand, for the flash fusing, the heat supply is very high by thermal radiation by flash lamp, but quite low pressure is applied only by toner's own weight.

Energy levels of heat supply, net heat for melting and pressing work

The energy levels at the condition of point A in Figure 3 are estimated in this section for a trial example.

From the point A in Figure 3, the heat supply is 6.8×10^3 J/m^2 Figure 5 shows an enthalpy change with temperature of a toner, which was published in Japanese literature [2]. In the present report, this data is used for rough estimation of the toner thermal absorbed energy level. Tg in Figure 5 means glass transition temperature of the toner. Toner melting behavior appears in the higher temperature than Tg. An extended line from a region below Tg, which is shown as dashed line, means an enthalpy without affection by meting. Therefore a difference between enthalpy with melting, shown as solid line above Tg, and the dashed line shows the level of the absorbed heat used for melting. In another literature [3], interface temperature between toner and paper at the end of the nip region is calculated as around 125 $^\circ C$, which conditions are 190 $^\circ C$ of heat roll temperature and 14 ms of nip period. Therefore average temperature in the toner layer is assumed roughly as 140 $^\circ C$ in the present report. From the data in Figure 5, the toner absorbed heat at 140 $^\circ C$ is led as 0.85×10^5

J/kg. Assuming toner fused solid layer thickness on paper as 5µm, unit kg toner covers 180 m^2. Therefore, absorbed heat for melting can be derived as 470 J/m^2 (= $0.85x10^5$ (J/kg) / 180 (m^2)). Comparing the heat supply and the absorbed heat for melting, quite large difference is found. It is derived that the absorbed heat for melting is only 7% of the heat supply in this estimation. It is surprising that the most thermal energy supplied to toner is not used for melting.

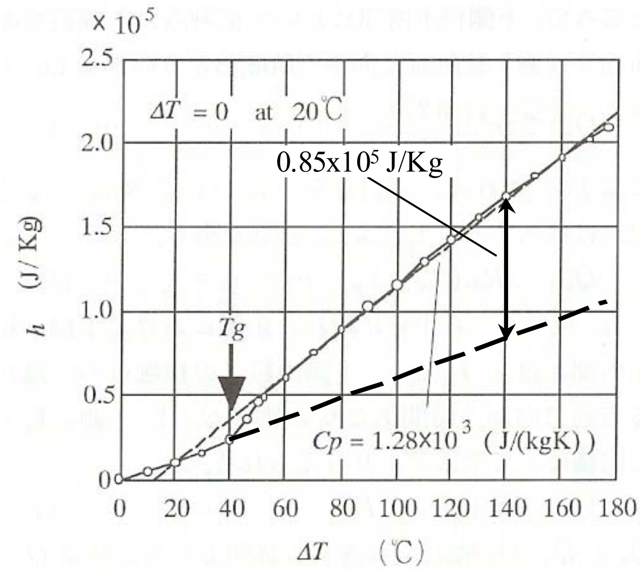


Figure5 . Enthalpy Change of Toner.

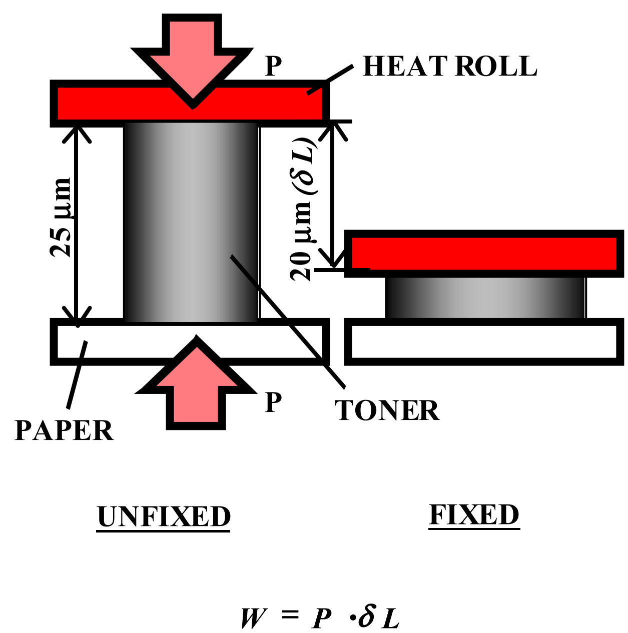


Figure6. Estimation of Pressing Work for Toner.

Figure 6 shows a model for deriving the pressing work. Work can be derived from an applied force and object's moved distance. Multiplication of the force (*P* if unit area) and deformed distance (δL) is resulted in the pressing work for fixing. The distance can be estimated between toner heights before and after fixing. It is assumed as 20µm ($20x10^{-6}$ (m)), derived from the difference between 25µm of unfixed and 5µm of fixed states. For the nip pressure, P, $3.3x10^5$ N/m^2 is applied from the point A of Figure 3. Thus, the pressing work is derived as 6.6 Nm/m^2
(=$3.3x10^5$ (N/m^2) x $20x10^{-6}$ (m)).

Comparing to the absorbed heat for melting, the pressing work is quite small. It could be considered that it means that functions of heat and pressing are different as written in foregoing section. In the prior study[1], the author supposed that total energy of heat and pressing work determined the fusing. However, it may be revised so that the energy should be evaluated separately.

Conclusions

The prior Japanese study [1] for energy in fusing has been reviewed. And then, the model for heat and pressing work has been examined in the present report. As a result, the followings are supposed.

The absorbed heat for the toner melting is surprisingly smaller than the heat supply. And, the pressing work is much smaller than the absorbed heat. It is supposed that functions of heat and pressing are different and it might be hard to discuss about the total energy of the heat and the pressing work for determining the fusing.

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Author Biography

Teruaki Mitsuya was born in Japan in 1957. He received his BE, ME and Dr. Eng. degrees in 1980, 1984 and 1997, each other. He has been researching and developing electrophotographic imaging technologies in Hitachi, Ltd. from 1984, California Inst. Tech. from 1994, Hitachi Koki Co., Ltd. from 1995, Hitachi Printing Solutions, Ltd. from 2002, Ricoh Printing Systems, Ltd. from 2004 and Ricoh company, Ltd. since 2008. He is a P.E.Jp qualification holder. He is members of IS&T, ISJ, ASME, JSME, etc.