Dimensional Analysis on Toner Fusing Process

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Abstract

The final step in xerographic process is the fixing of toner to the substrate. A traditional way to achieve this is to utilize the so-called hot roll fuser. It comprises a hollow aluminum alloy tube with a halogen lamp heater inside and a rubber back-up roller. Two rollers with the springs loaded at both ends form a nip region, where the toner particles are heated, pressed and fused. In this paper, we utilize the Buckingham P1 theorem to analyze and to find two dimensionless groups that control the fusing quality of toner with hot roll fuser. They are Pt^2/MD and T/T_a where P is the average nip pressure; t is toner residence time; M is the developed mass of toner per unit area on the substrate; D is the average diameter of toner particle size and T; T_a are the fusing temperature and ambient temperature respectively. Some experiments are made to correlate these two dimensionless parameters with fusing quality.

Introduction

The final step in xerographic process is the fixing of toner to the substrate. A traditional way to achieve this is utilizing the so-called hot roll fuser which comprises a hollow alloy tube with a halogen lamp heater inside and a rubber back-up roller. Two rollers with the springs loaded on both ends form a nip region, where the toner particles are heated, sintered, spreaded and penetrated into the substrate. The fusing of toner within the nip region is complicated and mainly controlled by the toner properties and the process parameters such as the nip pressure, nip residence time and the hot roll surface temperature.

Some work have been done to correlated these parameters with fusing quality. Prime[1] showed that the fixing quality is related to a parameter pt^2, where p is the nip pressure and t the nip residence time. Britto[2] made the dimensionless analysis through the use of partial differential equations that define the flow and heat transfer phenomena in the toner layer during the fixing process. The relationship between the fusing quality and the parameter pt/μ (μ is the viscosity of melted toner) was done in Britto's work.

In the present work, we utilize the Buckingham PI theorem to make dimensional analysis on the fusing parameters and toner properties and find two dimensionless groups-Pt^2/MD and T/Ta. The functional relationship between these two groups and fusing quality is determined by experiment.

Dimensional Analysis

The coalescence, spreading and penetration of toner in the fixing step is governed by the heat transfer and fluid flow phenomena in the nip region. The parameters controlling these phenomena are toner and process properties, as listed in Table 1. To analyze these parameters, first, we focus on some kind of toner which has the same percentage of ingredients but different diameter of particle size. The parameters that control the toner fusing process are simplified to ρ, **D**, **T**, **P**, **t**, **Ta**, and **H**. We can represent the fusing quality or fixing strength (**K**) as

$$\mathbf{K} = \mathbf{f}_1(\rho, \mathbf{D}, \mathbf{T}, \mathbf{P}, \mathbf{t}, \mathbf{Ta}, \mathbf{H}) \tag{1}$$

where **H** is the toner pile height. It is noted that the product of ρ by **H** can be replaced by the developed mass of toner per unit area on the substrate (**M**), i.e. ρ * **H** = **M**. Equation (1) can be rewritten as

$$\mathbf{K} = \mathbf{f}_2(\mathbf{D}, \mathbf{M}, \mathbf{T}, \mathbf{P}, \mathbf{t}, \mathbf{Ta}) \tag{2}$$

Secondly, we utilize the Buckingham PI theorem to make dimensionless analysis on the parameters of equation (2) and find two dimensionless groups—$\mathbf{Pt^2/MD}$ and **T/Ta**. Therefore,

$$\mathbf{K} = \mathbf{f}\ (\mathbf{Pt^2/MD}, \mathbf{T/Ta}) \tag{3}$$

The numerator of the first dimensionless group ($\mathbf{Pt^2}$) in equation (3) is consistent with Prime's[1] work. Some experiments are performed to correlate the functional relationship of equation (3).

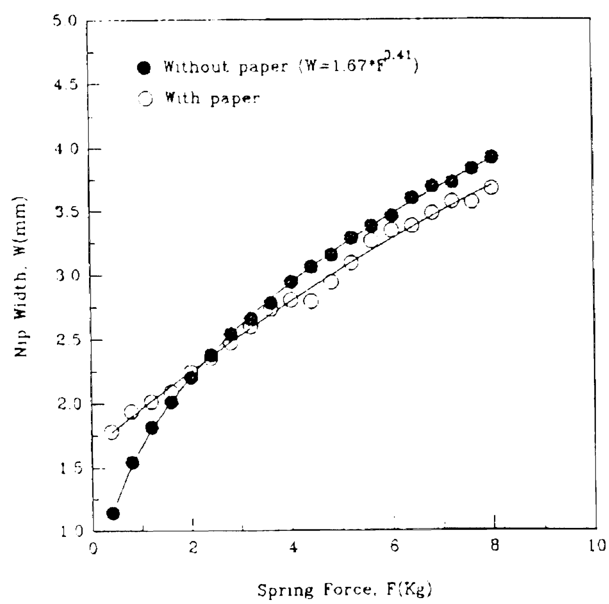

Figure 1. Nip width as a function spring load (Elastomer hardness = 25 Shore A).

Experimental Work

To determine the average nip pressure (**P**) and the residence time (t), we must first determine the nip width as a function of back-up roll force. The measurement of nip width was done by coating the back-up roll with unfused toner and sticking the double-faced adhesive tape to the hot roll. The two rolls were then brought together under the prescribed loading on both ends. The width of toned image on the adhesive tape was, in fact, the nip width. In the analysis of fusing parameters, we set up an experimental apparatus including the fusing and developing station. The fusing speed, hot roll surface temperature and back-up roll force are adjustable. The toner tested in the system was mono-component, non-magnetic type. The fusing quality (fixing strength), **K**, of fused sample was determined by adhesive tape peeling test. The adhesive tape used here was the 3M Scotch Tape 810, and the fusing quality is defined as the ratio of optical density (OD) of the image before and after of tape peeling off. The OD value of the samples image were measured by the Macbeth RD 949 densitometer.

Results and Discussions

Figure 1 shows the variation of nip width (**W**) as a function of spring load (**F**). The curve marked 'with paper' means that there exists one sheet of paper (0.1 mm thick) between the hot roll and back-up roll. The two curves are noted to be equal within the normal design region of spring force (1.5 to 3.5 Kg). Therefore, we use the equation, $\mathbf{W = 1.67*F^{0.41}}$, for the calculation of nip width.

The variation of fusing quality (**K**) with respect to the fusing time and hot roll surface temperature is shown in Figure 2. It is noted that the fusing quality is deeply affected by the fusing time. The curve can be regarded as linear before achieving the design criterion of fusing quality, say 80%. The fusing time required to achieve the design criterion is interpolated from Figure 2 as 44, 52 or 60 msec when the hot roll surface temperature is 190, 180 or 170°C respectively.

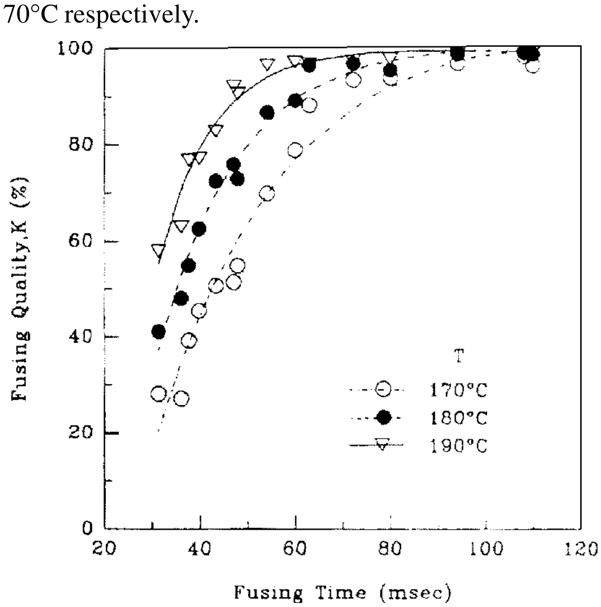

Figure 2. Variation of fusing quality with respect to the fusing time and hot roll temperature.

Figure 3 shows the functional relationship of equation (3) with respect to the different fusing grade. The fusing quality marked in the figure are interpolated from the original data. When the value of $\mathbf{Pt^2/MD}$ is less than 1.5×10^6, the fusing quality is strongly dependent on these two groups, **T/Ta** and $\mathbf{Pt^2/MD}$. But if it is larger than 1.5×10^6, **T/Ta** is the only group that controls the fusing quality. And the smallest value of **T/Ta** needed to achieve the design criteria of fusing quality (80%) is noted to be 6.2 in the figure. For designing a fuser for a 8 PPM machine, the value of Pt^2/MD needed to satisfy the criteria (K = 80%) is about 0.7×10^6 when T/Ta is 7.2 (i.e. T = 180°C). This implies that the spring force is 2.7 Kg and the fusing time is about 53 msec. This agree well with Figure 2.

Table 1. The toner and process properties affecting the fusing process

Toner Properties	Process Properties
ρ: Density	T: Hot Roll Surface Temperature
κ: Thermal Conductivity	P: Average Nip Pressure
μ: Viscosity	t: Residence Time
Cp: Specific Heat	H: Toner Pile Height
Tg: Glass Transition Temperature	Ta: Ambient Temperature
D:Diameter of Toner Particles	

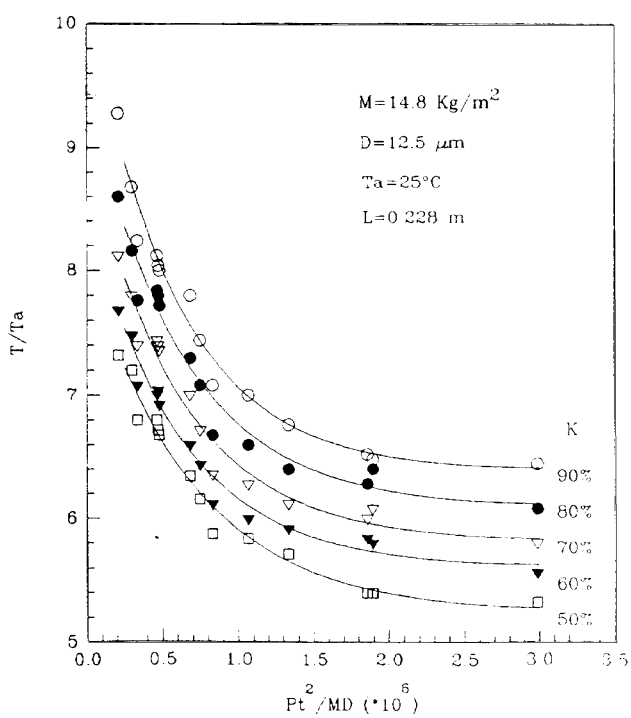

Figure 3. Functional relationship of equation (3) w.r.t. the different fusing grade (The dimensions used here are P: Pascal, t: sec, M: Kg/m², D: m, T: °C, and L is the length of back-up roll).

Conclusions

Fusing quality for a hot roll fuser in laser printer is governed by two dimensionless groups—Pt^2/MD and T/Ta. The functional relationship between these two groups with respect to the fusing quality is obtained by experiments and can be applied to determine the optimal spring force of fuser at various fusing speed and fusing temperature.

References

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