Electrophotography : Effects of Printer Parameters on Fusing Quality

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ABSTRACT

Toner fusing is a critical step for achieving good print quality in electrophotography. In most of the printers, heat and pressure bond toner to paper in a fusing nip is formed by two rolls. The fusing quality depends not only on melting characteristics of the toner and on paper properties but also on printer parameters such as the temperature of the hot roll, pressure and time in the fusing nip, lubrication and hardness of the rolls. An experimental fusing device allowing independent temperature adjustment of the hot roll, pressure in the nip, speed and lubrication with silicon oil has been designed and used for studying the influence of printer parameters on toner fusing quality. Results of experiments are presented and discussed on different theoretical models.

INTRODUCTION

Toner fusing is the last step in electrophotographic printing and is critical in achieving good print quality. The most common fixing method is hot roll fusing where heat and pressure between two rolls bond toner to paper. These rolls are covered with a more or less deformable layer of rubber to form a fusing nip that improves contact and dwell time (Fig. 1).

The first description of the fixing process was established by Lee(1) who defined the following three main steps:
sintering of toner particles,
spreading of sintered toner and
penetration into the media.

The author insists on the fact that good toner adhesion can be obtained only if good wetting is achieved, which depends on toner surface tension and viscosity. The fixing process is usually delimինted by two critical temperatures:
a low temperature below which toner neither sinters nor adheres to paper and
a high temperature above which toner becomes too liquid and loses its cohesion without detaching properly from the hot roll. These two temperatures are called "cold offset temperature" and "hot offset temperature", respectively.

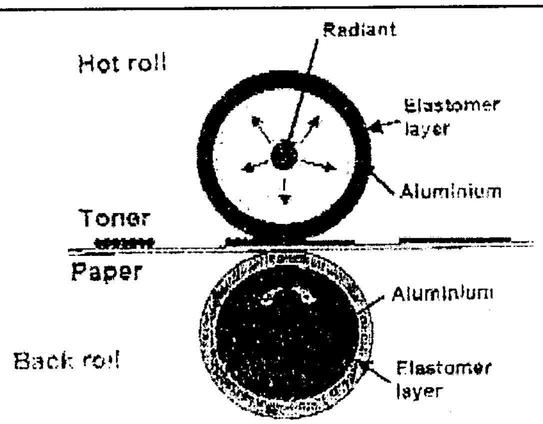

Fig. 1 Schematic view of a hot roll fusing nip

The influence of the main printer parameters: temperature of the fusing roll, dwell time and pressure in the nip, have been studied by several authors (5). Usually, the tests for determining toner adhesion are basic giving only semiquantitative results. Thus, a more precise and reproducible test was necessary. There was also a need to vary the main printer parameters, independently. This is impossible on most commercial printers (pressure and speed are fixed and, most of the time, fusing roll temperature cannot be adjusted by the operator.

Thus, we developed a test to determine tonner adhesion based on an IGT picking test and an experimental fusing device where temperature of the hot roll, pressure and speed could be subjected to a large range of variations. The results presented in this paper were obtained using this test and this experimental fusing device.

EXPERIMENTAL

Experimental fusing device

An experimental fusing device was designed by detaching the existing fusing station of an Oce 2050 printer. The motor of the fusing roll was changed and equipped with a speed variator so that dwell time could be varied. A sensor was added to facilitate temperature regulation of the fusing roll. The spring, orginally responsible for the pressure, was replaced by a pneumatic jack so that pressure in the fusing nip could be varied from 2 to 30N/ cm, 35 N/cm being the original pressure in the 2050 printer. Characteristics of the experimental fusing device are presented in Table 1.

Tabe 1 Characteristics of the experimental fusing device

Hot roll diameter	50 mm
Nip length	330 mm
Hot roll hardness	94 ShA
Back roll hardness	94 ShA
Hot roll temperature	from ambient to 250°C, +/-2°C
Linear speed	1 to 25 m/min, +/-0,2 m/min
Linear pressure	2 to 30 N/cm, +/-2 N/cm

A4- sheets, with unfused toner on them, were prepared with the 2050 printer by stopping between the transfer step and the fusing step, The settings of the printer were maintained at nominal values so that a constant thickness of toner was deposited on the paper. The thickness of this toner layer was controlled during the trials at 10 μm ± 1 μm after fusing.

Toner rheology

The toner used in the 2050 printer is a styreneacrylate based, two -component toner. Its viscous behaviour was determined with a parallel plates, rotating rheometer (Texas Instrument Carri-Med CSL 2500), equipped with a high temperature module. The upper plate is 2 cm in diameter and the gap between the plates is 300 μm. Measurements were only possible for low shear rates, due to high toner viscosity, and were carried out between 0 and 6 s in 60 seconds at four different temperatures: 140, 160, 180 and 200°C.

Paper

The paper used for the study was a 80 g/m², commercial, copy paper made of chemical, bleached pulp with approximately 20% calcium carbonate filler. After toner deposit, sheets were conditioned for 24 hours at 23°C, 50% RH before being introduced into the experimental fusing device. After fusing, sheets were again conditioned for 24 hours at 23°C, 50% RH before measuring toner adhesion.

Test for determining toner adhesion

The European Standard ENV 12283 "Determination of toner adhesion" was adapted to measure toner adhesion. This Standard is based on the submission of a solid area to the IGT picking test at constant speed with medium viscosity oil. The adaptation of the test consists in accelerating the picking test speed. This modification allows quantification of higher toner adhesions.

RESULTS AND DISCUSSION

Toner viscosity

Like many polymers, the toner studied has a shear thinning behaviour: viscosity decreases with shear rate. At each temperature, a new toner sample was used and shear rate applied to the toner from 0 to $6s^{-1}$ for one minute while shear stress was measured. The results are presented in Fig. 2 where the value of 0, $5s^{-1}$ was chosen to plot toner viscosity in relation to temperature.

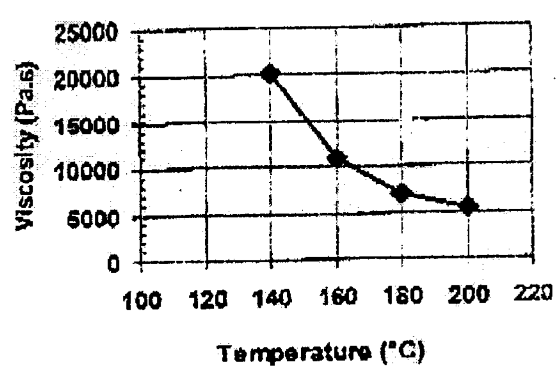

Fig. 2 Toner viscosity and temperature

The viscosity value at 140°C is 20280 Pa.s and conforms to the values obtained at this temperature by Majava (6) and Moriyama(7) who carried out rheology measurements on black commercial toners. Temperature influence on viscosity can be modelised using Eyring's law (8). It is based on the theory of occupied and empty sites that randomly move in the fluid and can be written as follows:

$$\eta = C.\exp\left(\frac{E_o}{R.T.}\right) \qquad \text{(Eqn. 2)}$$

where η is the viscosity. C a constant, E_o the activation energy, R the constant of perfect gases and T the temperature in K. E_o is the energy necessary for a macromolecular segment to overcome the energy barrier between two close sites. For the toner studied, the calculated value of E_o is 35.6 kJ/mol.

Tabe 2 Trials with experimental fusing device

Series	Linear pressure N/cm	Linear speed m/min	Hot roll Temp. °C	Nip pressure (MPa)	Dwell time mg
1.	20	10.5	variable 140 to 240	0.53	21.3
2.	20	5.3	veriable 140 to 240	0.53	42.3
3.	20	15.8	variable 140 to 240	0.53	14.2
4.	10	10.5	variable 140 to 240	0.3	18.4
5.	20	variable 3.2 to 25.2	180	0.53	8.8 to 70.0
6.	variable 4.8 to 23.9	10.5	180	0.18 to 0.62	16.9 to 22.5

Influence of printer parameters

6 series of tests were done with the experimental fusing device modifying linear pressure, linear speed and hot roll temperature as presented in Table 2. The average pressure in the nip has been calculated by dividing the linear pressure by the nip width. This depends on the linear pressure which was determined using nip prints with carbon paper. The dwell time was calculated by dividing the nip width by the linear speed.

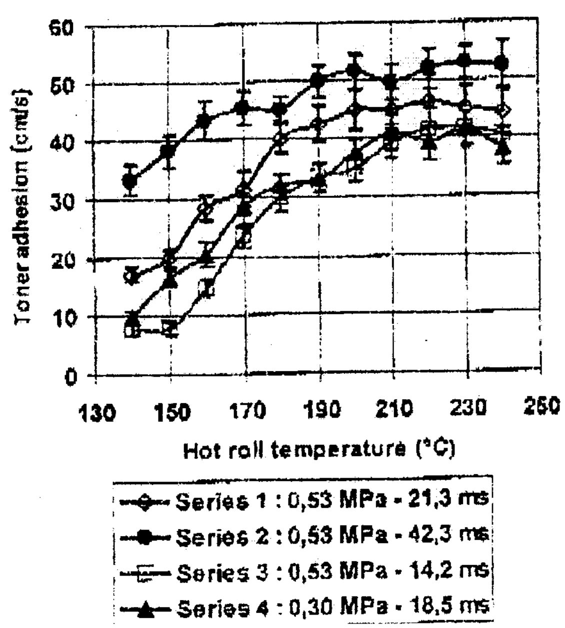

Fig. 3 Toner adhesion and fusing roll temperature

Influence of hot roll temperature

The toner adhesion measurements obtained with series 1 to 4 are plotted with respect to the temperature of the hot roll in Fig. 3. The four curves have the same behaviour and can be divided in two parts: for temperatures inferior to 190°C, toner adhesion increases constantly with the hot roll temperature, then the slope decreases. A steady value is reached and temperature increase no longer corresponds to adhesion increase. The trends observed conform to expectations. Whatever the fusing roll temperature, toner adhesion is improved by the increase in dwell time and by the increase in average pressure in the nip.

The images of Fig. 4 are scanning microscope photographs of solid areas of printed toner fused in different conditions of hot roll temperature and dwell time. Particles of toner can be individually distinguished in the images corresponding to low fusing roll temperature or to short dwell time. The sintering of these toner particles is not completed. On the two other images, the toner layer is smoother, more homogenous, and the toner behaves like a continuous film.

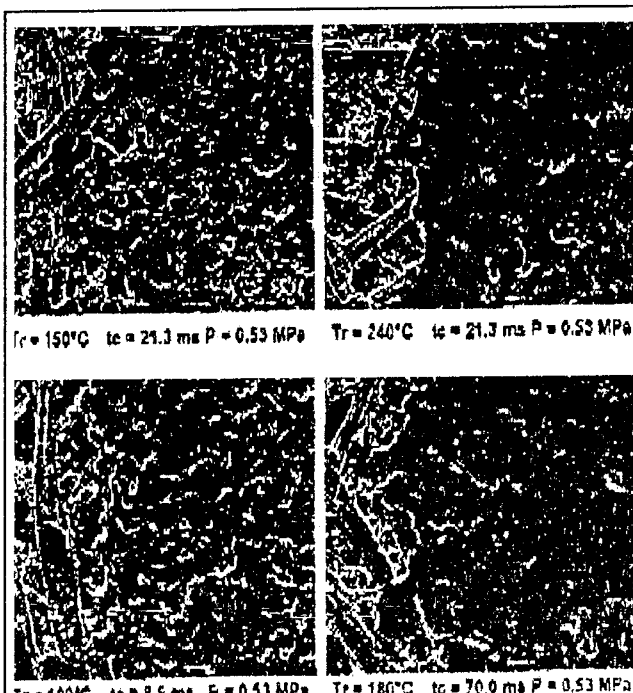

Fig. 4 Microscopic views of fused toner

Influence of dwell time

The toner adhesion measurements obtained with series 5 and 6 are plotted with respect to the temperature of the hot roll in Fig. 5. Average nip pressure is constant (0.53

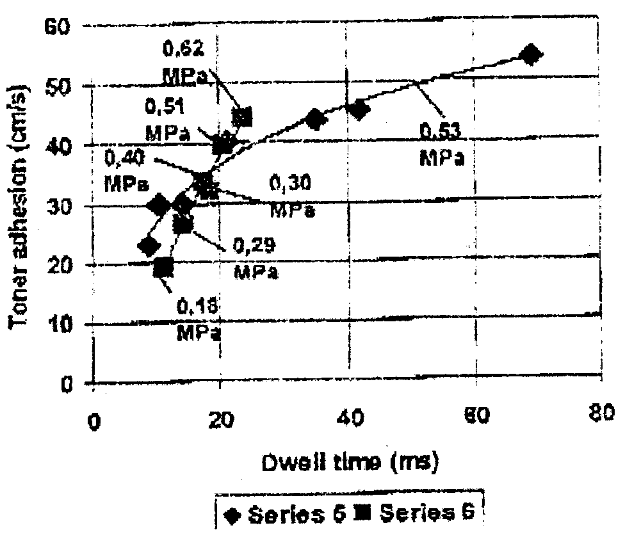

Fig. 5 Toner adhesion and dwell time

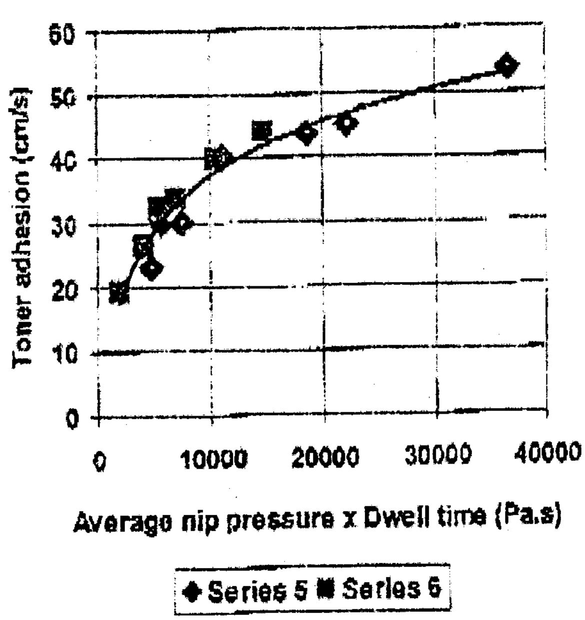

Fig. 6 Toner adhesion and product pressure x dwell time

MPa) in series 5 and dwell time is the only variable whereas pressure and dwell time are variable in series 6. When hot roll temperature and pressure remain constant, the influence of dwell time on toner adhesion can be approached by a logarithmic relation. When the pressure is lower than 0.53 MPa, adhesion is worse for the same dwell time and conversely. Thus it was relevant to plot toner adhesion in relation to product (Pressure x dwell time), as it has already been suggested by Prime (2) Fig. 6 shows the results.

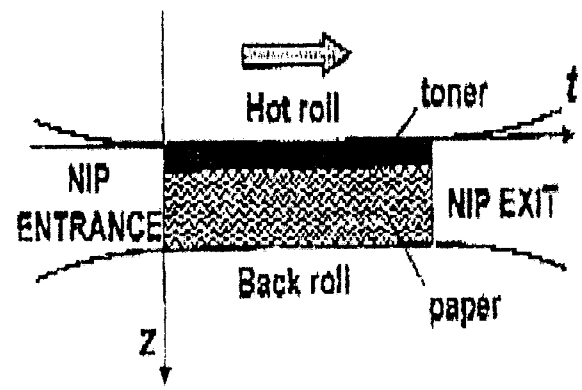

Fig. 7 Schematic view of fusing nip for heat transfer modelisation

Both series are then combined on the same curve, meaning that for a given hot roll temperature, toner fixing quality depnds on the product (pressure x dwell time). To take the influence of hot roll temperature into account, it was decided to divide this product by the viscosity of the toner in contact with paper. The number thus obtained is a dimensionless number characterising the opposition between factors aiding toner penetration (pressure and dwell time) and factors preventing penetration (toner viscosity). Eyring's law can be used to calculate the viscosity of toner at the toner/paper interface, provided that the temperature of this interface is known. A modelisation of the thermal transfer in the fusing nip was done to obtain this temperature.

Heat transfer in fusing nip

The field of calculation is comparable to a parallelepiped as shown in Fig. 7.

The axis represents the spatial dimension in the machine direction, between o and 1π (nip width.). It is equivalent to a time dimension t, where t is equal to $\frac{x}{v}$, v being the linear speed. t varies between o and t (dwell time). The z dimension varies between o and e_p e being the sum of toner thickness e_t and paper thickness e. The y dimension coressponds to the length of the fusing roll. As this dimension is infinitely large compared to the others, the problem can be reduced to the t and z dimensions.

The thickness of toner and paper are considered to be constant during the fusing step. This is obviously not the truth because paper is compressible and toner sinters during fusing, pushing the air present in porosity. Many authors have worked on this particular problem by considering the paper and toner layers as an arrangement of several layers of toner, air and paper (9-10). Our approach is based on thermal calculations in calendering nips (11).

The heat transfer equation is given by Fourier's law which is the following.

$$\frac{\delta^2 T(z,t)}{\delta z^2} = \frac{1}{D}\frac{T(z,t)}{\delta t} \quad \text{(Equation 2)}$$

where T(z,t) is the temperature at the point of co-ordinates (z,t) and D the thermal diffusivity of the material, defined by $D = \frac{\lambda}{\rho.C_p}$ where λ is the thermal conductivity, ρ the density and Cp the heat capacity of the material.

The boundary and initial conditions are the following :

For z = o, whatever t : T (o, t) = Tr (temperature of fusing roll)

For z = e whatever t : T(e. t) = Tb (temperature of back roll)

For t = o, whatever z : T(z, o) = Te (temperature of at the nip entrance)

Thermal properties of toner and paper were also considered as constant during the fusing step. Values of diffusivities of 1.10-7 m²/s for the toner and of 2.10-7 m²/s for the paper have been found in literature [9] and [12] respectively).

Eqn. 2 has been solved numerically using the method of finite differences. The values of the parameters used in the different calculations are presented in Table 3.

Tabe 3 Parameters for heat transfer modelisation

Hot roll temperature Tr	140 to 240°C
Back roll temperature Tb	57 to 72°C
Temperature at nip entrance Te	23°C
Toner diffusivity	1.0-10⁹ m²/s
Paper diffusivity	2.0-10⁷ m²/s
Toner thickness	10 µm
Dwell time	8.9 to 70.0 ms

The profiles of the temperature at the toner/paper interface (co-ordinates (e_t t_c) have been plotted with respect to dwell time and are presented in Fig. 8.

The behaviour of the curves shows that the temperature at the toner/paper interface increases during the first milliseconds of contact. After 15 milliseconds, the temperature of the interface nearly reaches a steady value. Viscosity of the toner is low and it can flow through the pores of the paper surface before being cooled at the nip exit. The values of temperature reached by the toner /paper interface at the nip exit have been extracted to calculate the toner viscosity value using the Eyring law

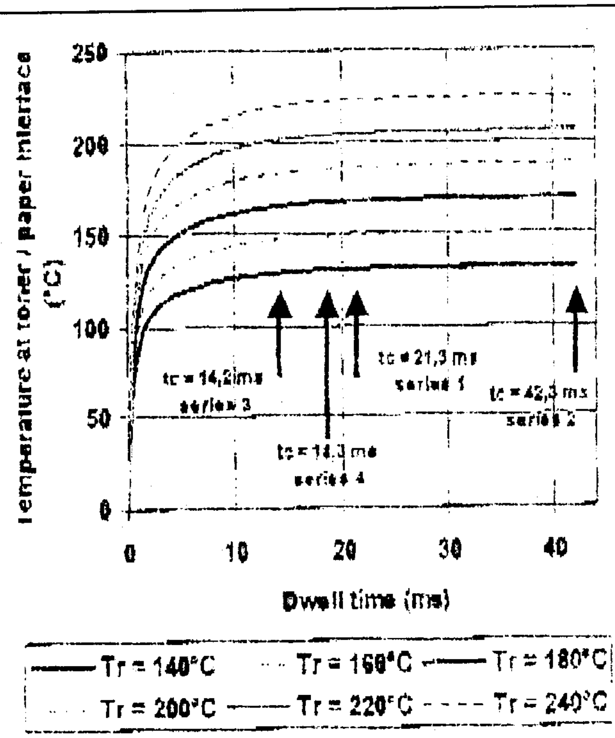

Fig. 8 Temperature at toner/paper interface

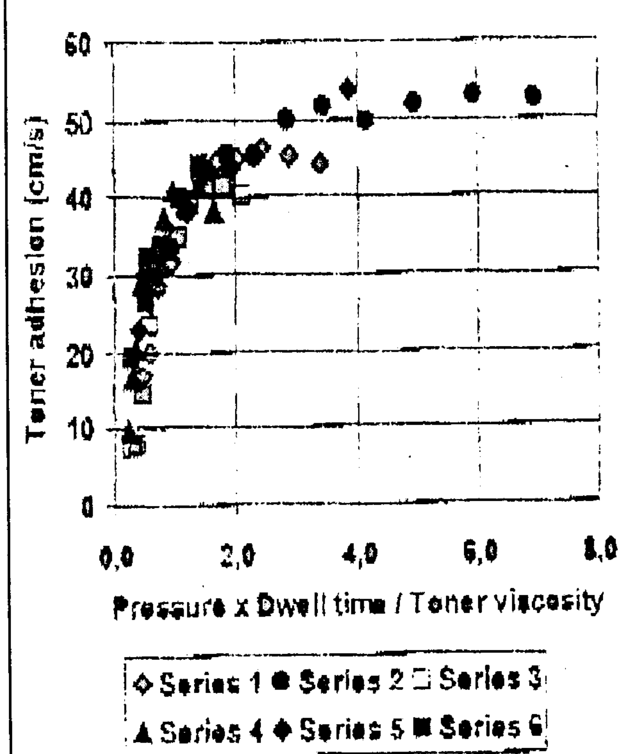

Fig. 8 Temperature at toner/paper interface

(Eqn. 1). Then, for each experimental condition, this was used to calculate the dimensionless number ζ given by:

$$\zeta = \frac{P_{av} \cdot t_{0}}{\eta(Ti)}$$ (Eqn. 3) where P_{av} is the average pressure in the nip in Pa.

tc is the dwell time in s

η (Ti) is the toner viscosity at maximum temperature reached by the interface toner/paper during the fusing step, in Pa.s.

Toner adhesion is plotted in relation to the dimensionless number ζ in Fig. 9.

The influence of dimensionless number on toner adhesion is clear. The higher ζ the value the more dominating the factors promoting toner adhesion are. A decrease in toner viscosity promotes toner penetration as it promotes a better wetting and a better access to the pores of paper surface. Dwell time aids toner adhesion because of its influence on the degree of temperature reached by the toner/paper interface and because it allows a longer duration for toner to flow before cooling pressure applied also promotes toner penetration. Strongest toner adhesions have been obtained with longest dwell times and conversely. Provided that hot roll temperature is sufficient, toner adhesion can be consequentily improved by prolonging dwell time.

CONCLUSION

The toner adhesion test used allows quantifying the influence on toner adhesion of the main printer parameters in hot roll fusing. As expected, toner adhesion is improved when the temperature of the fusing roll, nip pressure and dwell time are increased. This last parameter appears as the most decisive and an improvement of fusing stations could consist in enlarging nip width. However, as toner adhesion stabilises when the temperature of the fusing roll is increased, improvement of toner adhesion by increasing temperature is limited. It was found that toner adhesion can be correlated to a dimensionless parameter that takes into account nip pressure, dwell time and temperature of the fusing roll, provided that other variables of the fusing station, paper, toner and toner thickness are held constant. This dimensionlesss number indicates the opposition between factors supporting toner penetration (pressure and dwell time) and factors preventing it (toner viscosity). Here, toner "penetration" must not be understood as penetration into the capillaries of the paper but into open pores of paper surface.

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