Adhesion of Electrophotographic Toner on Paper***

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ABSTRACT

Electrophotography is one of many non-impact printing processes. Fusing is the final stage in an electrophotographic printer or copier, which determines print quality properties, such as fixing strength, glossiness and density of the image. The thermal properties of the toner are a compromise between being soft enough for the fuser, but hard enough so the toner particles are not fused on the photoreceptor of the development system, or in storage.

The aim of the work was to determine toner adhesion under different fusing conditions. Prints were made with a commercial printer with one common black toner on a commercial paper. The prints were taken removed from the printer before the fusing stage. Non-contact fusing was accomplished in an oven. The melting energy and viscosity of the toner were measured. The adhesion of the toner on paper was determined by testing the oven-fused prints with a tape test method developed for this work.

Melting starts from the surface of toner particles and toner particles first start to cohere after which the melted toner film start to adhere to the paper. The results of this study show that the adhesion of the toner depends on its viscosity and melting temperature. The adhesion of the toner was complete when it was fully melted.

The findings indicate that the networking is very effective way to produce common material and share knowledge products between organizations. There are some problems caused by information and communication technology. Most important is, however, people's attitudes towards collaboration. Without positive attitude the collaboration may not work.

INTRODUCTION

Fusing is the final process in an electrophotographic printer or copier /1/, which determines print quality properties such as fixing strength, glossiness and density of the image /2/. The thermal properties of the toner are a compromise between being soft enough for the fuser, but hard enough so the toner particles are not fused on the photoreceptor at the development stage, or in storage.

The toner's rheological properties must be optimised to allow coalescence, spreading, and finally penetration into the paper. In this study, the forming of adhesion in the non-contact fusing stage, simulated in an oven, is discussed. The objective of this work was to determine the effect of the toner's melting temperature on the image fixing ability of the toner on paper.
MATERIALS AND METHODS

Materials

Prints were made with a commercial colour laser printer with black toner on a commercial paper (80 g/m²). The prints were removed from the printer before fusing. Non-contact fusing was accomplished in an oven.

Thermal measurements

The thermal analysis of the toner was made with a Mettler DSC30 device connected to a computer with a special thermal program. The change in heating energy was observed as a function of temperature.

Toner samples were 5-8 mg. The heating rate was 10°C/min and the temperature range 30-300°C. Measurements were made in closed crucibles through a pinhole (constant pressure during heating). The melting energy of the toner was observed as a function of temperature.

Viscosity measurements

The viscosity of the toner was measured using a Bohlin VOR rheometer with a high-temperature unit and a cone/plate-geometry. The viscosity measurement was made in oscillation mode at 10 Hz frequency. The measurement temperature range was from 80 up to 200°C.

Adhesion measurements

A modified tape test was used for the adhesion measurements. In this test, a tape was attached to the fused image by a controlled and repeatable pressure. Then the tape was pulled from the paper by a controlled and repeatable force, speed and angle. All this was done with a device designed according to ASTM D1894 (Standard Test Method for Static and Kinetic Coefficients of Friction of Plastic Film and Sheeting). The tape used for the measurements was 3M Scotch 810 (the width of the tape was 19 mm).

The tape was peeled off the print which was placed on the plane of the device (a friction meter, Atsfaar, Societa per azioni, Milan, Italy). The average value of force and optical density before and after the tape test was observed. The width of the test area was 19 mm. The tape was pulled from the paper by a controlled and repeatable force, speed and angle. The adhesive tape was pressed onto the print (constant pressure) and onto the other end of the movable part of the friction meter /Figure 1/.

![Figure 1](Principle of adhesion test method.)

The change in density of the print before and after the test represents the adhesion percentage, \((D_{after} / D_{before}) \times 100\). The average value of force and optical density before and after the test was observed.
RESULTS AND DISCUSSION

Thermal changes in the toner during the fusing process can be divided into three stages /Figure 2/: 

1. Warming  
   • Increase in temperature of toner particles and paper
2. Softening  
   • Melting of the toner starts from the surface of particles and toner particles start to cohere and adhere to each other.
3. Melting  
   • Partly melted toner Adheres to the paper.

At stage 1 shown in Figure 2, the temperature rises from room temperature to about 70°C, but no melting occurs in this range. In stage 2, the toner starts to melt on the surface (from about 70°C to 85°C). When the toner is heated for the first time, the softening (glass transition) temperature is higher than when it is heated for the second time, when the toner is already Glass-like. Toner particles adhere to each other And a greater proportion of toner adheres to the tape. Toner particles first cohere, and in stage 3, the toner starts to melt and adhere to the paper, too. In this stage, the adhesion on paper is almost complete. The toner continues to penetrate and spread As the temperature increases.

![Figure 2. Melting of toner on paper.](image1)

The melting stages of the toner can be seen from the viscosity curve (Figure 3). Viscosity is at the maximum level, when the toner particles adhere to each other (stage 3 is about to begin). At this stage, the toner is completely Liquid-like, and from this point, its viscosity develops according to the Arrhenius equation as a function of temperature:

\[ h = \Delta e^{E/R \cdot T}, \]  

(1)

Where A is a constant (frequency factor), E constant (activation energy), R constant (gas constant) and T is Temperature.

![Figure 3. Viscosity of toner as a function of temperature.](image2)
The toner melts to a liquid-like state and its viscosity is at its highest when about 20% of the melting energy has been consumed (Figure 4). Because the change in energy ($\Delta E$) depends only on the change of temperature:

$$\Delta E \propto m\Delta T.$$  \hspace{1cm} (2)

![Viscosity and Melting Energy](image)

*Figure 4.* Connection between viscosity and melting energy.

The viscosity of the toner behaves according to equation (1), starting from the temperature at which the viscosity has reached its maximum value as a function of melting energy.

The consumption of melting energy increases when the toner becomes completely liquid-like (about 130°C). The consumption of melting energy as a function of temperature is shown in Figure 5.

![Melting Energy vs Temperature](image)

*Figure 5.* Melting energy of toner as a function of temperature.

The adhesion of the toner to the paper is weakest when the surfaces of toner particles start to adhere to each other. After the glass transition temperature has been reached when the toner has softened, the toner starts to adhere to the paper. Optical density and print adhesion as a function of fusing temperature are shown in Figure 6.
Before fusing occurs, the adhesion of toner to paper depends on the roughness of the paper and electrostatic forces. Before any real melting has occurred, the adhesion to tape is significantly greater than the adhesion to paper. When the toner starts to soften, it first coheres with toner particles, which is why the measured adhesion of prints is very poor when the toner has softened (glass transition, about 75°C). When the toner starts to melt, the adhesion to paper increases.

Figure 7 shows the connection between adhesion and adhesion force at four temperatures. The adhesion force increases from the glass transition temperature to the temperature of complete melting.

The following stages are seen:

1. (65°C). Unfused. The interaction of the toner layer with the paper involves some adhesion from the electrostatic transfer force. The forces are stronger than the toner-toner coherence. Also, the tape is in contact with upper layer only.
2. (75°C). At the interface between the toner layer and the paper, the toner starts to adhere stronger to the paper because of the rise in the paper's temperature, but still the toner is a powder in this temperature range.
3. (80°C). In the first melting stage, the toner particles tend to adhere to each other to create a film, overcoming the earlier adhesion. This is adhesion the weakest point, with the tape in contact with the surface layer of one part of the image.
CONCLUSIONS

Fusing is the final process in an electrophotographic printer, which determines print quality properties such as fixing strength, glossiness and optical density of the image. The fixing strength can be estimated with adhesion measurements. The adhesion and adhesion force of the toner depend on the degree of melting of the toner during oven fusing.

If the toner has not melted enough, the adhesion on paper is very poor. It was clearly observed that the first part of fusing energy is consumed by the toner particles in cohering and adhering to each other. After that, the rest of the energy is consumed to complete the melting, lowering the viscosity and allowing the toner to penetrate into the paper. Too high fusing temperature has a negative effect on print quality, even if the adhesion of the toner is at its maximum.

The optimal fusing temperature of the toner can be estimated from the viscosity and the melting energy consumption of the toner as a function of temperature.

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