Print Quality in Hot Air Fusing of Toners

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Abstract

Experiments were conducted to find how quality achieved in fusing dry toner prints by hot air compares with quality in hot nip fusing. Quality was measured as toner adhesion, macro and micro scale optical print properties and visual quality. It was concluded that hot air fusing offers some potential advantages which are to a large extent dependent on toner properties.

Introduction

At the moment the most commonly used method of fusing dry toners to paper is hot nip fusing where toner images are thermally fused on a substrate in a nip between a heated roll and a pressure roll. This construction has certain limitations especially in high speed printer systems. The dwell time required to achieve a desirable level of fix is extremely short so unfavorable phenomena like picking, offset transfer and paper wrapping may occur. Non-contact fusing systems do not have these drawbacks. Hot nip fusing is, however, considered to be more energy efficient than non-contact fusing methods.

Hot air fusing is a non-contact fusing method[8]. A hot air fusing system would consist of an air circulation pump, a heating element and nozzles through which the air impinges on the print in a closed chamber. The system has the inconvenience that all the parts in contact with hot air must be heated sufficiently. The dwell time can be varied by the length of the heating zone.

Preliminary experiments showed that toner adhesion in hot air fusing of dry monocomponent toners develops at lower process temperatures than in nip fusing. The preliminary experiments aroused an interest in hot air fusing. The aim of this research is to find how feasible hot air fusing is compared with hot nip fusing from the standpoint of image quality. At the outset it was hypothesized that impingement of hot air on a dry toner layer might cause toner spreading and result in higher edge raggedness.

The study also clarifies how toners with divergent properties behave under different fusing conditions. Moreover, the known significance of the paper was taken into consideration by using two paper grades.

Methods

The samples used in the fusing experiments were printed with a 600 dpi, 8 ppm electrophotographic printer. The speed translates into a linear speed of 0.04 ms^{-1}. Fusing by hot air was carried out with a hot air oven designed originally for laboratory scale drying experiments of offset printing (air volume per nozzle 200 l/min, nozzle width 8 mm, three nozzles). Paper travels in the oven at 0.04 m/s and the length of the heating zone is 200 mm. In the experiments of this study, air was blown through three nozzles at a temperature of 120–200 °C. The same temperature range was used in hot roller fusing in the low speed printer.

Toner adhesion was determined by the adhesive tape peeling test. Adhesion was defined as the percentage ratio between the macro scale optical densities before the test and after peeling. Two commercially available electrophotographic paper grades, uncoated (80 gm^{-2}) and coated (80 gm^{-2}), were used. The PPS (10 kPa) roughness values of the papers were 5.55 and 3.48 µm respectively. The tested black dry toners[5] were magnetic monocomponent toners and were commercially available for the electrophotographic printer of the study. None of the toners were "glossy" toners as such.

Table 1. Toner properties

	Toner A	Toner B	Toner C	Toner D
Resin content of toner (%) /heating rate 20 C°/min/	58.0	61.0	69.0	52.0
Glass transition temperature (Tg C°) /heating rate 20 C° /min/	65.5	60.9	67.7	57.0
Phase Angle (°) /10 Hz, 180 °C/	52.4	60.0	51.8	38.1
Viscosity (kPas) /0,04 1/s, 180°C/	3.5	1.2	1.4	25.8
Particle medium(µm)	6.3	11.3	13.1	6.4

The thermal weight loss behavior of the toners was measured to determine resin content by thermogravi-metrical analysis with a Perkin Elmer 1020 thermal analyzer. The melting behavior of the toner samples was characterized by glass transition temperature (Tg) as measured by using a Mettler 30 differential scanning calorimeter. The rheological measurements were performed in plate-plate measuring geometry on a Bohlin VOR Rheometer equipped with a high temperature unit. Viscosity (0.04 s^{-1}) and oscillation tests (10 Hz, 5% amplitude) were carried out as function of temperature (130–200 °C). The relatively low shear rate used in the viscosity measurements is representative of shear rates in low speed electrophotographic printing processes. The particle size measurements of the toners were performed with Microgop 2000 S-image-analysis system attached to a light microscope and a CCD-camera. A compilation of the toner measurements is given in Table 1.

Optical quality of printed samples was measured on macro and micro scales. The number of replicate measurements was ten in all cases. Macro scale density was measured using a Macbeth RD-918 densitometer and gloss (75°/75°) using a Macbeth Labgloss glossmeter. The micro scale measurements made from solid prints had the purpose of quantifying the small scale reflectance variation of the prints. In the measurements, the illuminated samples were imaged using a CCD video camera with a pixel size of 2.6 μm. The image was digitized to 256 × 256 pixels and hence each replicate measurement corresponded to an area of 0.7 × 0.7 mm. From the images two-dimensional reflectance power spectra were computed. The parameters derived from the spectra included total energy (variance), called subsequently solid area noise, and its distribution in five frequency bands. The bands are the following: Band 1 = 1.5 – 38.2 mm^{-1}, Band 2 = 38.2 – 76.4 mm^{-1}, Band 3 = 76.4 – 114.6 mm^{-1}, Band 4 = 114.6 – 153 mm^{-1}, Band 5 = 153 – 191 mm^{1}. Quantification of the spectrum was carried out to simplify analysis of the frequency structure of noise.

Edge raggedness was measured from printed lines in the micro scale measuring conditions described above. Edge raggedness was computed as the standard deviation of the actual edge from a best straight line fit.

The solid area prints were also visually evaluated by ten subjects using the ranking method.

Results

The level of toner adhesion increases with temperature more efficiently in hot air fusing than in hot nip fusing (Figure 1). This is the case on both of the papers. On the coated paper, the level of acceptable fusing quality can be achieved at a lower temperature. In hot air fusing, 130°C on the coated paper and 150°C on the uncoated paper, was sufficient to achieve 100% adhesion in the test. In nip fusing the respective temperatures were 150°C and 180°C.

In nip fused prints a slight decrease in density could be noticed with a rise in the fusing temperature over the whole of the temperature range[2]. By contrast, a rather rapid increase in hot air fused print densities was evident for toners B and C when temperature was above 160 °C. In both fusing methods, print gloss is seen to increase with fusing temperature (Figure 2) over the whole temperature range. A very strong increase is evident in hot air fused prints of toners B and C after 160 °C.

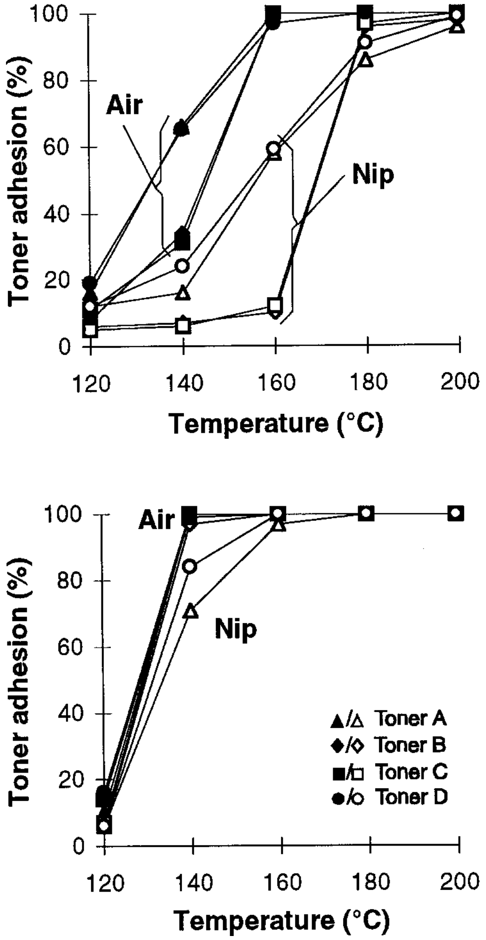

Figure 1. Relation of solid area toner adhesion and fusing temperature for uncoated paper (left) and coated paper (right).

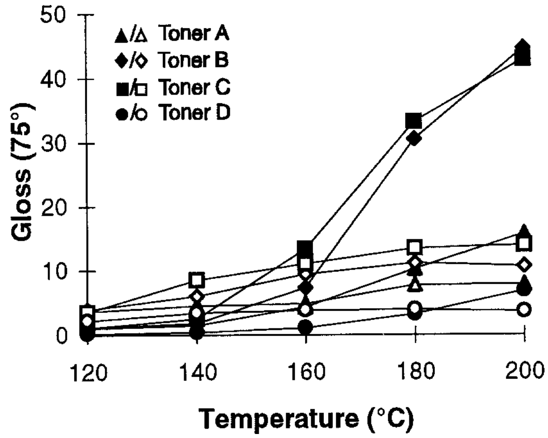

Figure 2. Relation of solid area gloss and fusing temperature with coated paper. Hot air fusing: black symbols, nip fusing: white symbols.

According to the measurements, the prints tend to become more uneven (Figure 3) with a rise in the fusing temperature. Unfused toner layers are the least noisy. The increase in noise is more marked in hot air fusing than in nip fusing. At practical fusing temperatures, however, there is no major difference between the two fusing methods. The increase in noise at rising temperatures is clearly dependent on paper and toner properties. The prints on the uncoated paper were more uneven. The ranking of the toners with respect to noise at increasing temperatures is the same in nip fusing and hot air fusing.

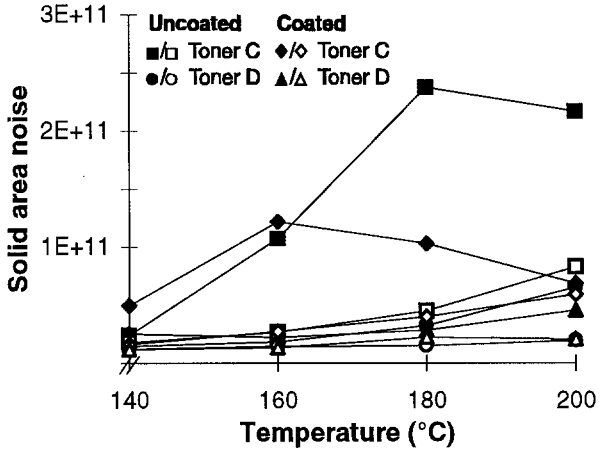

Figure 3. Influence of fusing temperature on solid area noise. Hot air fusing: black symbols, nip fusing: white symbols.

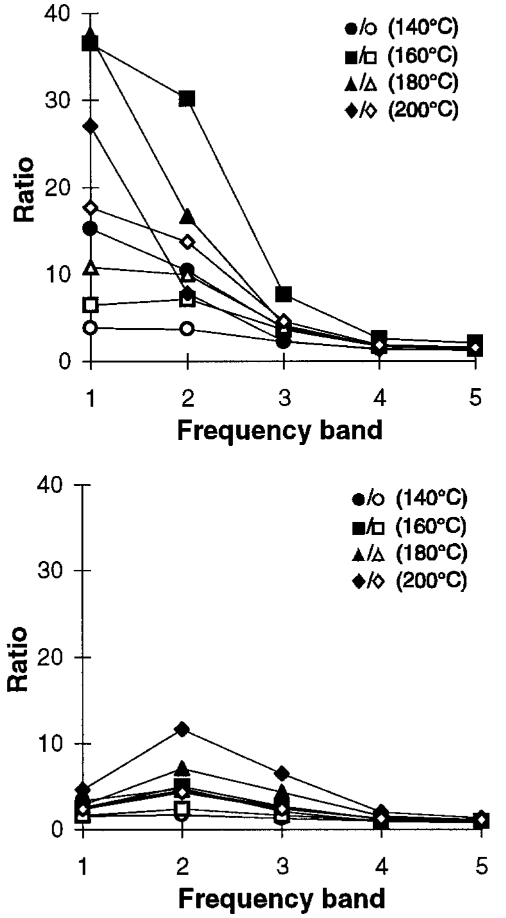

Figure 4. Relative solid area noise (variance ratio of noise in fused and unfused prints) in different frequency bands. Toner C (top) and toner D (bottom). Hot air fusing: black symbols, nip fusing: white symbols.

As temperature is raised, noise increases predominantly within frequency bands characterizing lower frequencies (bands 1, 2 and 3) than those representing the toner particle sizes (bands 4 and 5). This is illustrated in Figure 4 which shows the ratio of noise in fused prints and the respective unfused prints. In fact, high frequency noise is virtually not increased at all.

Nip fusing and hot air fusing do not seem to differ as far as the shape of the spectral ratio vs spatial frequency curves is concerned. There are, however, distinct differences between the toners (cf. Figure 4) which each proved to have a characteristic curve shape of its own. The reason may lie in toner specific toner/paper interactions or film forming.

The edge raggedness values extended over a range of 3.5 to 6.8 µm (Figure 5). Hot air fusing tended to produce more ragged edges than nip fusing, although there were exceptions. Unfused edges were the least ragged. The influence of the fusing temperature in the range of 140 – 200 °C was minor, whereas clear differences were evident between different toners and the two papers; raggedness was more marked on the uncoated paper.

The visual ranking data of the solid prints are shown in Figure 6. The hot air fused prints were evaluated as the best. Clearly, solid area noise, as measured in this study, has not been the decisive factor in the visual assessments. Instead it seems that gloss and density have played a more important role.

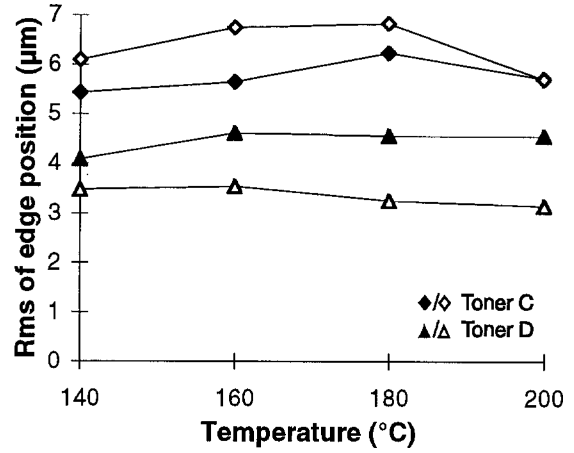

Figure 5. Influence of fusing temperature on edge raggedness. Hot air fusing: black symbols, nip fusing: white symbols.

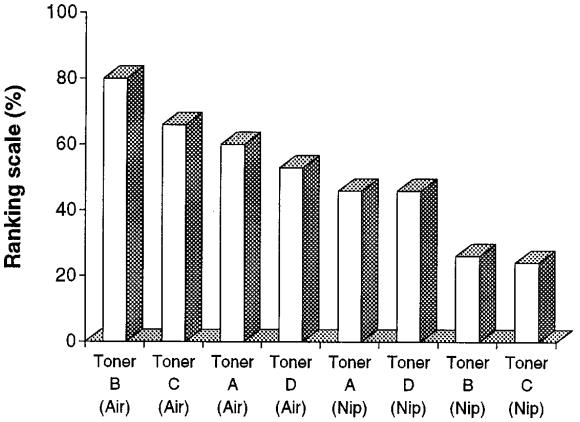

Figure 6. Ranking order of solid area prints. Temperature of fusing 180°C.

Discussion

The finding of this study that acceptable toner adhesion is achieved at lower temperatures in hot air than in nip fusing is an indication of heat transfer differences. Two factors may contribute to this: higher heat transfer coefficient of hot air and longer residence time in the hot air fuser. The difference between the efficiency of the methods was more marked on the uncoated paper, which was rougher. It is known that non-contact between paper and fuser roller tends to result in deteriorating fusing quality[3]. This gives grounds to believe that heat transfer differences play a part. The influence of the longer residence time appears to be self-evident.

The differences between the toners, with respect to the development of adhesion with rising temperature, were not unambiguously related to any measured toner property. Clearly, chemical composition, not analyzed in this study, is the major factor.

Generally speaking, the print properties varied over a wider range in hot air than in nip fusing. The rise in gloss at high temperatures, evident in Figure 2, is accompanied by a rise in density as Figure 7 illustrates. The levels of gloss exceeded those achieved today in high speed color electrophotography at best by some 20 gloss percentage units[1]. Without doubt, hot air fusing offers good gloss potential with suitably structured toners.

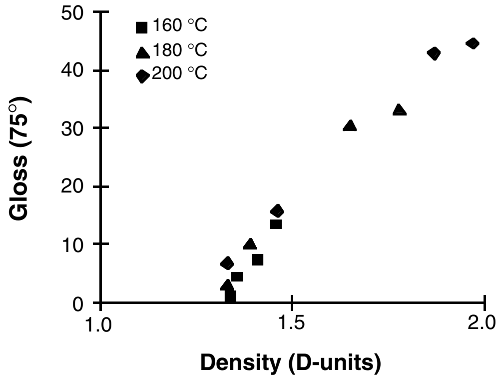

Figure 7. Relation of solid area density and gloss. Hot air fusing. Coated paper.

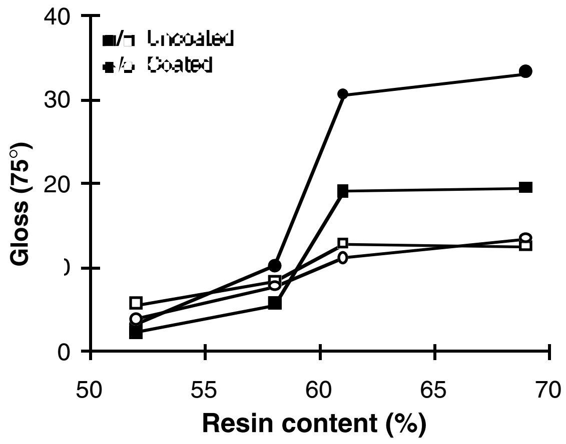

Figure 8. The influence of toner resin content on solid area gloss. Fusing temperature 180 °C. Uncoated and coated paper. Hot air fusing: black symbols, nip fusing: white symbols.

Of the measured toner properties, resin content is the one which best accounts for the density and gloss level differences of the toners (Figure 8). A higher resin content (within the range of 52 – 68%) is associated with higher density and gloss.

Of the toner properties measured, viscosity differences between the toners appear to predict how easily gloss develops with temperature (Figure 9); a low viscosity is advantageous. The influence of phase angle (cf. Table 1) proved to be consistent with the influence of viscosity. These observations agree with the established understanding of particle sintering and film formation[4]. Clearly the efficiency of heat transfer in hot air fusing aids film formation. It is envisioned that the gloss potential of hot air fusing could be utilized at otherwise practical fusing temperatures by taking it into consideration in the development of toner formulations.

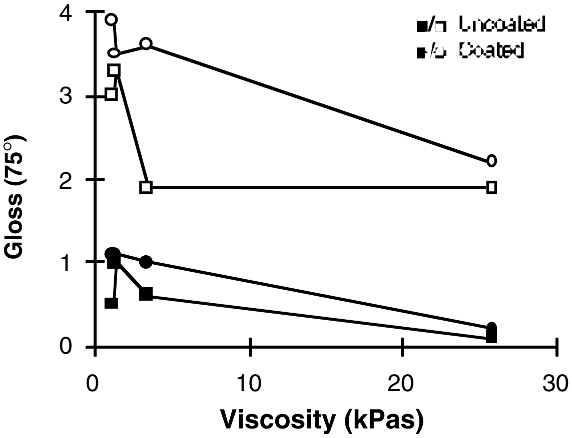

Figure 9. Relation of viscosity and gloss. Fusing temperature 120 °C. Hot air fusing: black symbols, nip fusing: white symbols.

Also, print noise in solid areas has some relation with viscosity; high viscosity is advantageous (Figure 10). This suggests that solid area noise is caused by either uneven toner penetration into the paper or viscosity-related film formation effects. The fact that the noise differences occur at low spatial frequencies does not favor either of these mechanisms over the other.

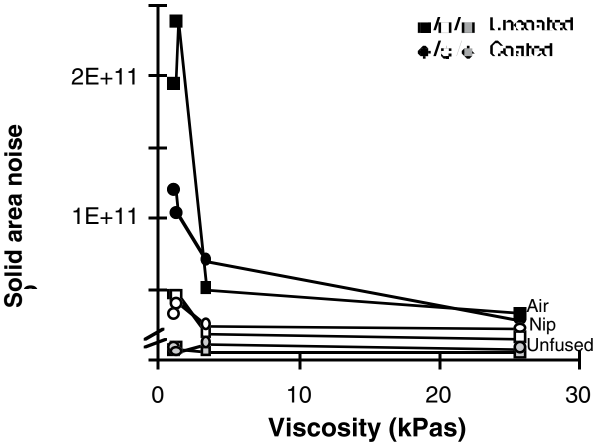

Figure 10. Relation of viscosity and solid area noise. Fusing temperature 180°C. Hot air fusing: black symbols, nip fusing: white symbols, unfused toners: gray symbols.

The observation that edge raggedness in fused images is higher than in unfused images is well known[6]. The fact that the fusing temperature has virtually no influence (cf. Figure 5) indicates that the fusing methods, nip pressure and air blow, cause movement of toner particles. Consistent with previous studies, edge raggedness tends to increase with a rise in particle size[7] (Figure 11).

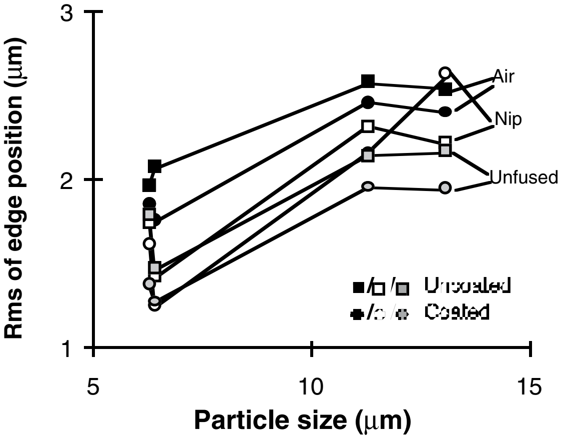

Figure 11. Relation of particle size and edge raggedness. Hot air fusing: black symbols, nip fusing:white symbols, unfused toners: gray symbols.

Conclusions

The data of this study suggest that hot air fusing offers some advantages over nip fusing, such as potentially lower temperatures and in some respects better optical quality. These are, however, obtained at the cost of the complexity and space requirements of the fusing equipment. This means that the practical potential of hot air fusing lies in high speed applications. Especially, it is hypothesized that high speed color printing applications could benefit from hot air type fusing.

Hot air and nip fusing do not seem to differ essentially as far as the overall mechanisms are concerned. The relative significance of the mechanisms at given fusing temperatures may, however, be different. Most notably, the efficiency of hot air fusing is accompanied by a higher gloss and density potential. Edge raggedness tends to deteriorate somewhat and instrumental solid area noise tends to increase. The overall visual appearance, however, improved. Observed differences between the tested toners were of such a magnitude as to suggest that with optimized toner formulation, the potential of hot air fusing can be utilized and its weak points eliminated.

References

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