Media/Toner Interactions in Laser Printing

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Abstract

According to CAP Ventures,[1] monochrome Print-on-Demand (POD) book publishing is currently a $10 bn industry growing at a rate of 10% each year. Such POD and other electro-photographic applications demand an exceptionally high degree of print resolution as well as good toner adhesion. Controlled particle size distribution of the toners, higher print speeds, and other advances in color laser printing are also placing special demands on the media used for printing. This paper attempts to separate the effects of three different fuser roll cover materials, which impact the nip dynamics, to the print resolution and uniformity as well as the toner adhesion to the substrate. The toner adhesion was characterized by Scanning Electron Micrographs (SEM's). A model has been developed to estimate nip residence time for the fuser roll covers. As shown in the model, this parameter can be affected both by roll cover design as well as print speed. In this limited study where the print speed was held constant and the nip residence time changed only due to roll cover design, it was shown to correlate well with print resolution as measured by image analysis techniques.

Introduction

Typical on-demand book publishing is an electro-photographic process in which a polyester based toner is applied to the substrate and is subsequently fused to the surface of the substrate. In such processes, uniformity of image and consistency from page to page in print quality is an important requirement. Print evenness, toner adhesion, and good optical quality of the print are essential. The output should be free of mottled appearance, have uniform optical density, and should be smear-free. Any deviations from these requirements can cause unacceptable print quality and customer rejections.

The fusing mechanism is a combination of pressure and temperature that is applied by the fuser rollers. Several of the past studies[2-5] have shown that the pressure applied by the fuser rolls on the substrate, the fusing temperature, and the speed of printing have an impact on the print quality. The speed of printing, in combination with the pressure on the rollers, determines the nip residence time. Exactly what aspect of this fusing technique (nip residence time or temperature) affects the print quality is not understood.

Past studies[2] showed that the roll covers affect the print quality. But no attempt has been made to quantify this. Also there have been no concerted studies that have been conducted that correlate the print quality with a process parameter, such as the nip residence time. For the first time a model is proposed to estimate the residence time of the substrate in the fuser roll nip. This parameter is a function of the print speed as well as roll hardness. The softer roll material provides a wider nip width than a harder material which in turn alters the nip residence time. Though print speed was not altered in this study, a good correlation exists between the nip residence time estimated for each cover material used and the print quality.

Fuser temperature was held constant in this study and calculations of the surface temperature with the three covers showed that there were no significant differences. The cover material was not sufficiently thick to make a difference. Future studies should address the nip residence time effects that result from both the change in print speed and roll cover design as well as quantify the temperature effects

Experiment

Uncoated paper (60 lbs/3300ft^2) was used in this study and the image printed using a LED high-speed 600 dpi printer operating at 750 impressions per minute using a polyester based toner. Three fuser cover materials were used in this study:

1. Perfluoroalkoxy (PFA) coated hard cover
2. Silicone rubber soft cover
3. Hybrid cover (which combines the artifacts of hard and soft rollers) with intermediate hardness

The fusing temperature was maintained at 216^{o}C. Identical images printed with these three fusing rolls were analyzed using Image-Pro software. Also identical spots were used to generate SEM images that reveal the toner anchoring on the fiber surface.

Theory

Table 1 summarizes the properties of the three cover material used in this study. The fuser roll diameter for all the conditions was 4" with a roller width of 19.5". According to studies available[6-10] the nip mechanics in a fuser roll are well represented by the Hertz theory. The nip width "w", which determines the nip residence time based on speed of printing, is given by this theory to be dependent on the load placed on the rollers and the elastic modulus of the cover material.

Table 1. Properties of Cover Materials and Nip Width Calculations

Cover Material	Shell Thickness (mils)	Elastic Modulus (psi)	Nip Width (inches) (calculated)
PFA Coated Hard Cover	4	70000	0.020
Silicone Rubber Soft Cover	8 – 10	600	0.217
Hybrid Cover with Intermediate Hardness	8–10 mils rubber with 1-3 mils PFA	2500	0.110

The nip width "w" can be represented by:

$$w = 1.6\ \sqrt{P*L*D_E / E_E}$$

where P is the load on the fuser rolls, L is the fuser roll width, D_E is the equivalent diameter defined as:

$$D_E\ = D_1 * D_2 / (D_1 + D_2)$$

and E_E is the equivalent modulus defined as:

$$E_E\ = E_1 * E_2 / (E_1 + E_2)$$

where D_1 and D_2 are the diameters of the nipped fuser rolls and E_1 and E_2 are the elastic modulii, respectively. The elastic modulus for the covers used in this study were obtained from available literature.[8-10] Based on the speed of printing and the length of the paper used, the nip residence time was calculated as follows:

Nip Residence Time (milliseconds) = (60* 1000* nip width)/(Print speed in ppm * Paper length)

Results and Discussion

The surface micrograph of the uncoated 60-lb/3300 ft^2 paper used in this study is shown in Figure 1. As can be seen there, the paper has undulations that are sometimes described as "hills" and "valleys". It can be seen that the fibers are bonded with a significant amount of voids which are filled partially with small particles of inorganic material. The inorganic materials are typically additives to the fibers that enhance optical or physical properties. The fibers are typically 1-3 mm in length and have a diameter of 30–50μm.

When a polyester toner (averages size of 7-12μm) comes in contact with this surface, the toner has to anchor to the surface consisting of the fibers and the voids. Such an anchoring mechanism could be both chemical and physical in nature. This adhesion that takes place subsequently is caused by the fusing action which is a function of the temperature of the fusing roll and the pressure applied on them. Essentially the toner is laid down on the paper to anchor it to the substrate surface by chemical and/or physical means followed by fusing into the substrate structure through the nip actions in the fuser rolls.

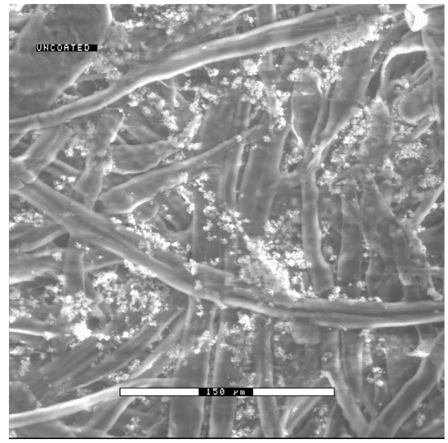

Figure 1. SEM image of the uncoated, unprinted paper.

Figures 2-4 show the toner lay on the surface of the substrate using three different cover materials described previously on the fuser rolls. These figures show that exactly how this anchoring takes place will determine the print quality of the image. It is evident from these images that, the image quality was acceptable, with uniform toner transfer, when using the soft fuser roll or the hybrid fuser roll compared to the hard fuser roll.

This observation from these SEM images can be explained as follows: The soft roller is always in intimate contact with the toner layer which results in good transfer efficiency and a softer image quality, while the hard rollers fuses well at the peaks in the paper and leaves the valleys under-fused. This results in mottled print appearance. With the soft and the hybrid fuser rolls, the roll surface is compliant with the paper surface and this helps the toner to be spread into the valleys of the paper where it fuses because of the heat supplied by the fuser roller.

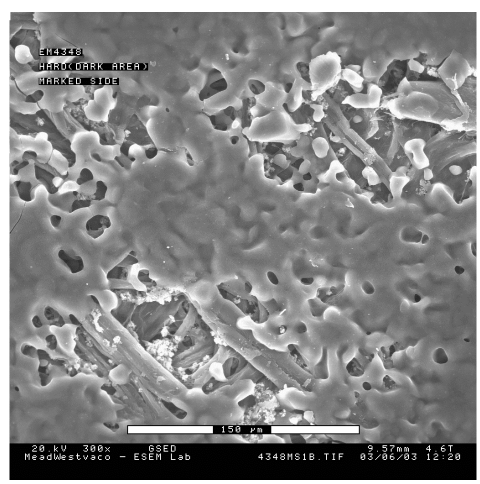

Figure 2. SEM image of toner lay using hard fuser roll

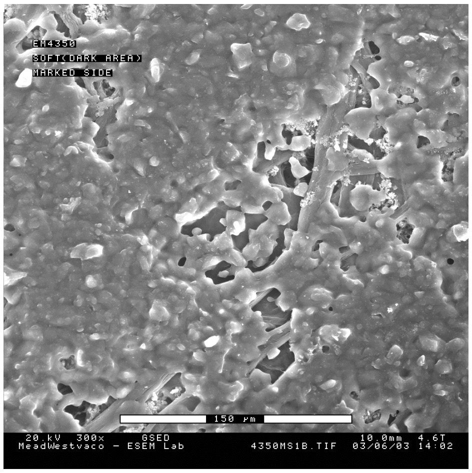

Figure 3. SEM image of toner lay using soft fuser roll

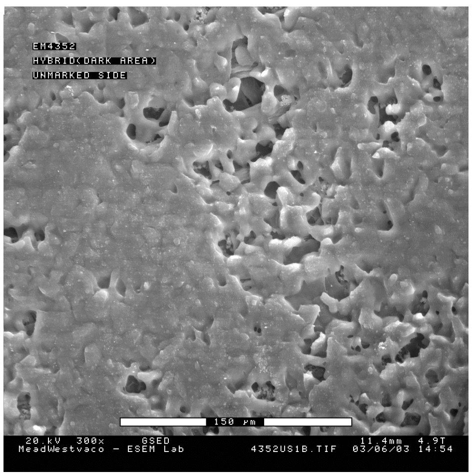

Figure 4. SEM image of toner lay using a hybrid fuser roll

As the papers were all conditioned to the same moisture, and the temperature of the fuser roll surface was not significantly different for each of the covers, it suggests that the nip residence time has a significant effect on the toner adhesion to the surface. With the improved coverage using the soft roll and the hybrid roll the paper does not exhibit a mottled appearance but a more even appearance.

Figures 5-7 show the solid print image at a magnification of 31X. Care was taken to evaluate the same section of the image in each sample. Visual examination of these images show that the image was mottled significantly with the hard fuser roll compared with the soft and the hybrid rolls.

These images were used to obtain a grey scale print mottle ranking that was plotted as a function of the nip residence time as shown in Figure 8.

Other that the fuser roll hardness the only difference that can be quantified is the nip residence time. Though the speed was not varied in this study the strong correlation between the print quality and the nip residence time is a factor that must be considered.

Figure 5. Print Mottle (@ 31X) of solid print area using a hard fuser roll.

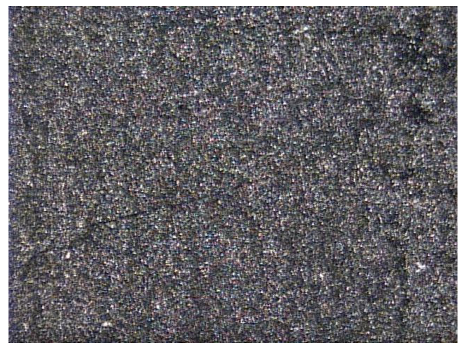

Figure 6. Print Mottle (@ 31X) of solid print area using a soft fuser roll

Figure 7. Print Mottle (@ 31X) of solid print area using a hybrid fuser roll

Future studies should include the data on speed changes for validating this observation. Clearly the soft rolls result in the best image quality but have a poor life. A hybrid cover with intermediate hardness seems like the best choice for fuser roll material. It is potentially possible to blend the polymers used in making the hybrid roll covers so that they maintain a good roll life while resulting in good print quality.

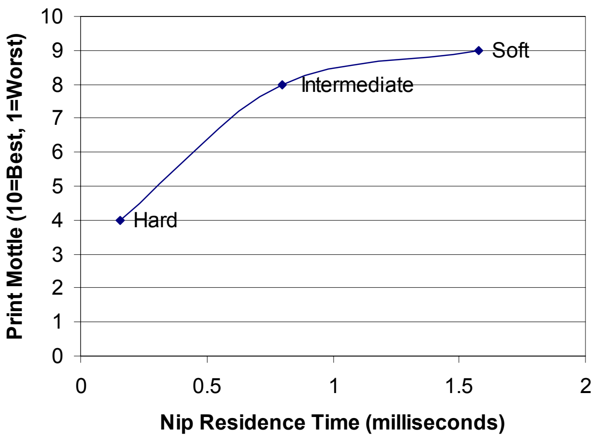

Figure 8. Print Mottle Ranking using Image Analysis for paper fused with hard, soft, and hybrid fuser rolls.

Conclusion

This study shows that roll cover design has a definite impact on print quality. If the speed of printing is held constant to maintain productivity, the hybrid roll covers have a clear advantage as they mimic the excellent print quality and good fusing of the silicone rubber rolls while they have the potential to have a long life like the hard PFA rolls. Future work should address on how best to make these hybrid rolls. It is possible to vary the thicknesses of the silicone rubber and the hard PFA coating to arrive at an optimal blend that results in good quality for solid prints produced in monochrome printing.

The study also shows that nip residence time could be an important parameter that needs to be optimized. This study is not complete because it did not include the effect of print speed. A more comprehensive study must be undertaken where the speed of printing is varied for each of the cover material used so as to truly quantify the effect of this important parameter.

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Biographies

Bhima Sastri received his B.S. degree in Chemical Engineering from IIT, Madras, India in 1982 and his MS and Ph.D. in Chemical Engineering from Rensselaer Polytechnic Institute in New York in 1987. He has worked with Westvaco (presently MeadWestvaco) Corporation since 1987, working in the Research Divisions at Covington, VA and Laurel, MD, for the Coated Papers Group. His current focus is on developing coated substrates for Digital Printing. From 1998- 2001 he was a Visiting Professor at IIT, Madras in the Chemical Engineering Department and also served as General Manager of R & D with ITC Ltd., in India where he lead the Research and Development group. He is a member of the AIChE and TAPPI organizations.

Velliyur Sankaran has worked on electrophotography for over 30 years. He has worked for IBM and Oce Printing Systems USA, Inc. Presently he has formed his own consulting company. He has published numerous papers and has 5 patents issued to him. He has an MS is Chemical Engineering and Polymer Science. He is a member of the IS&T.