Influence of Coating Ink Setting Rate on Ink Transfer

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Abstract: A recent ink transfer model (Xiang & Bousfield 2001 TAGA), that contains basic properties of ink and coating, was proposed to take into account of the effect of ink setting rate. In this work, three well characterized coated papers and two inks, with different internal resistances, are compared in terms of ink transfer. Papers are printed in the first nip and sent through second nip on a lab press. Ink transfer in the initial nip and the ink remaining after second nip are determined for all three papers and two inks. Ink transfer in the initial nip is found to be controlled by the setting rate of the coating, the roughness of the coating surface and the setting rate of the ink: fast setting results in a higher ink transfer. Ink remaining after second is also determined by the setting rate of the coating or ink. Fast setting ink reduces the effect of coating setting rate. Fast setting coatings reduce the ink effect.

Introduction

The amount of ink transferred to a coated paper surface has been found to be the key factor that determines the final print density, one of the most important criteria to evaluate print quality (Zang & Aspler, 1998). It is well known that this transfer depends on many aspects involved in printing process, such as printing speed, printing pressure, ink properties, and paper properties (Schaeffer, *et al*. 1963). However, the effect of coating properties, in particular coating ink setting rate, on ink transfer in multicolor printing has not been well documented in the past.

LePoutre and De Grâce (1978) found at low printing speed, that coating porosity and absorbency had little or no effect on ink transfer, print density and print gloss. However, recent work at much higher printing speed by Zang and Aspler (1995, 1998) has demonstrated that print density on coated papers with a similar

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surface finish is determined by the amount of ink transferred and under identical printing conditions more ink is transferred to more porous and more absorbent coatings with less latex contents. Ink transfer and print density in these studies were determined with a ***single nip or single color***. The real situation, where ink is transferred at the first printing unit, and may be partly transferred to the subsequent blankets, is not reported. The effect of ink setting rate on ink transfer is limited in these single nip tests. In a recent study by Xiang & Bousfield (2000a), a series of well-characterized model coatings were printed with several nips to study the effect of ink-coating interaction on final print density in multicolor offset printing. They found a similar result to those reported by LePoutre and De Grâce (1978) with single nip contact in that little difference in print density was found between the samples with different ink setting rates. With four nips, the final print density increases with increasing ink setting rate. These results suggest that the amount of ink transferred to paper changes in the final nips of multi-color. The final ink on the surface depends not only on the amount of ink on the plate but also on the ink-paper interaction/ ink setting rate.

Traditionally, experimental data of ink transfer are often interpreted with the Walker-Fetsko model (1953). In this model, ink transfer is divided into three components. Incomplete contact at low ink levels gives insufficient ink to satisfy the ink-immobilizing capacity of paper. The non-immobilized free ink between the plate and the paper surface can be divided with any constant fraction, depending on the ink-paper-press interaction. The Walker-Fetsko model or its simplified model has been widely used to interpret ink transfer phenomena in single color printing. Many modified models have been proposed by other researchers (Karttunen, *et al*, 1971; Bery, 1978; Yamazaki, 1991; Zang, 1993) to better interpret the ink-paper interaction during printing, mainly by modifying the coverage function or introducing other new features. Mangin *et al.* (1982) did a critical review on major ink transfer models and found that all were able to fit certain experimental data, but none of them accurately described the physical phenomena involved in ink transfer. Zang (1993) proposed a modified model by introducing a new splitting function that not only fitted the experimental results well but also yielded realistic ink-transfer parameter. However, in the Walker-Fetsko equation or other modified equations, the effect of ink setting rate and the dependence of time ink transfer are not separately included. The immobilization function in these models is a complex quantity that combines the effect of the dwell time, paper porosity, pore size, and ink viscosity in a single nip. They cannot be applied to interpret the results reported by Xiang & Bousfield (2000a) in multi-color case and to evaluate the effect of ink-paper interaction/ink setting rate on ink transfer.

On the other hand, recent work has indicated that the ink setting rate depends on the coating pore structure (Xiang & Bousfield 2000b), the type of latex used in the coating layer (Purfeerst, *et al*. 1994, Triantafillopoulos and Lee 1996, Desjumaux *et al* 1998, Xiang *et al* 2003) and some internal resistance of the ink

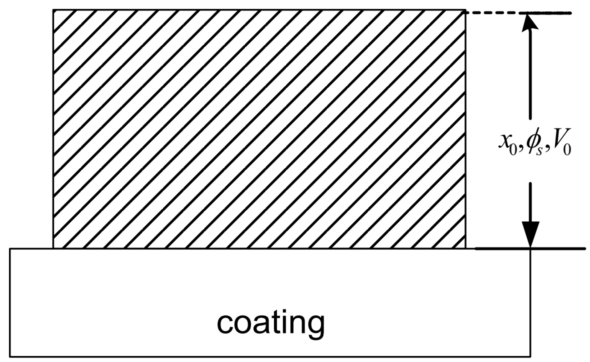
(Gros, *et al.* 2002). Repeated observations that small pores in the coating layer cause rapid ink setting compared to large pores are contrary to the Lucas-Washburn model, even when the results are normalized in terms of number of pores per unit area. Xiang and Bousfield proposed a model for ink setting that accounts for the resistance of the ink mobile phase to move through the ink layer (Xiang & Bousfield, 2000b). A hypothetical ink filtercake was suggested to form on the coating layer, and the correct trends of ink setting rate are predicted. Physically the model suggests that the driving force for ink setting is caused by the capillary pressure generated in the coating layer while the resistance to absorption is dominated by the flow through the ink filtercake. This model is well supported by the experimental results published recently by Preston, *et al.* (2001) and their empirical equation proposed. In a recent work, based on their ink setting model, (Xiang & Bousfield 2001) proposed a new ink transfer model to link the ink transfer in multiple nips to coating ink setting rate. As schematically shown in Figure 1, a filtercake forms on the paper surface as ink mobile phase penetrates into the coating. The thickness of free splitting film in a printing nip depends on the growth rate of the filtercake. The ink volume per unit area transferred to the paper surface [$V(t)$] can be expressed as:

$$V(t) = V_0 f + \frac{\phi_f (1-f)}{\phi_f - \phi_s} V_p \tag{2}$$

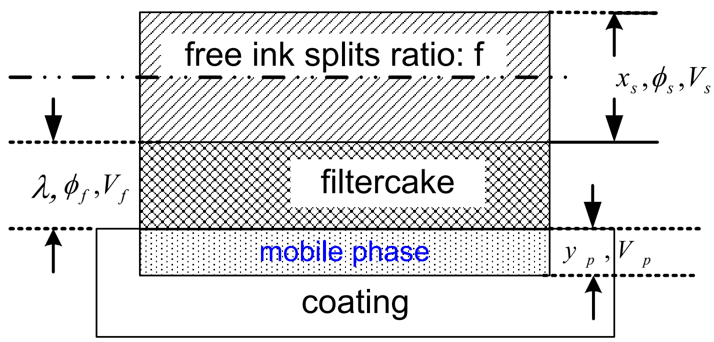
where V_0 is the initial volume of ink per unit area, V_p is the volume of mobile phase per unit area absorbed by the coating, ϕ_s and ϕ_f are the volume fraction of solid in the ink and ink filtercake, respectively. The volume of mobile phase per unit area absorbed by the coating can be given as below based on our previous work (Xiang & Bousfield 1999):

$$V_p = \sqrt{\frac{Rt\gamma\varepsilon^2 \cos\theta}{2\eta\left(1 + \frac{\varepsilon^2 R^2 \phi_s}{8K\phi_f (1-\phi_s)}\right)}} \tag{3}$$

where K is Darcy coefficient, R is the radius of the capillary, γ is surface tension, θ is the contact angle, and η is the viscosity of the fluid phase.



a. Initial Ink Film at Time $t=0$



b. Time $t=t_i$

Figure 1. Formation of filtercake and free ink splitting

By combining Eq. (2) and Eq. (3) and replacing the volume of ink per unit area with the thickness of ink, we obtained the thickness of ink layer transferred to coating surface $y(t)$as

$$y(t) = fx_0 + C\sqrt{t}(1-f) \tag{4}$$

where x_0 is the initial thickness of ink film on the printing plate, f is the split ratio of the free ink, and

$$C = \sqrt{\frac{4Kt\gamma\phi_f^{\,3}(1-\phi_s)\cos\theta}{\eta\phi_s R(\phi_f-\phi_s)}} \tag{5}$$

where C is defined as the ink-paper interaction parameter which is a measure of ink setting rate. C contains the physical properties of the ink and substrate that can be measured independently. Eq. (4) states that the amount of ink transferred on to the paper is proportional to the amount of ink on the printing plate, the ink-paper interaction parameter/ink-setting rate, and the square root of the dwell time in the nip or the contact time before splitting. This new model was found to predict a correct trend of our indirect experimental observation that fast setting surface gives higher print density, an indication of higher ink transfer, than slow setting surface (Xiang and Bousfield 2000a). However, direct evidence on how ink setting rate influences ink transfer in multiple nips is lacking. In this work, three well characterized coatings with different ink setting rates and two inks with different internal resistances are compared to examine the effect of ink setting rate on ink transfer in multiple nips. Ink transfer in the initial nip and the ink remaining after the second nip are determined by printing these coatings on a laboratory printing tester.

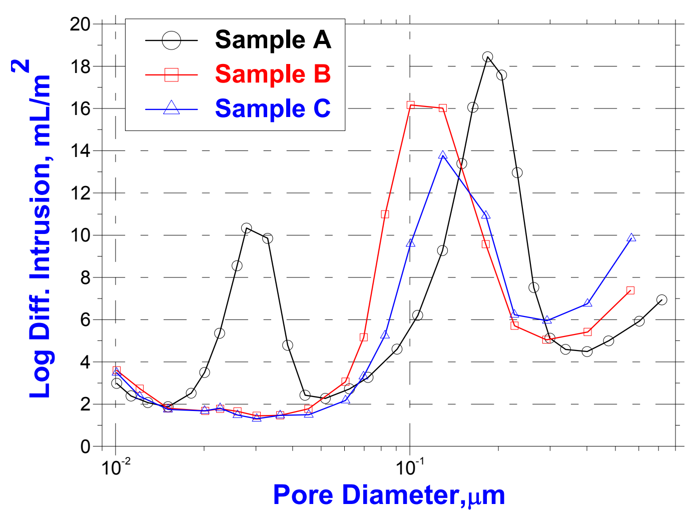


Figure 2 Pore size distributions of three samples

Experimental

Three coated papers differing in ink setting rates were used. Sample A (162 g/m^2) is a HP Inkjet Flyer and Brochure paper and has a very fast setting coating layer. Samples B (146 g/m^2) and C (175 g/m^2) are coated offset papers by Smart Paper. Sample B has a more open coating layer and lower gloss than sample C. These samples were characterized for roughness and pore structure. The roughness was measured with a diamond tipped stylus profilometer (Alpha Step

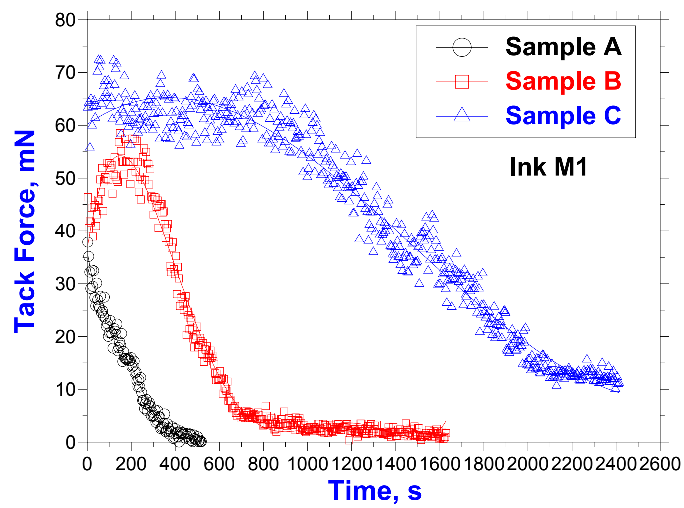
200, Tencor). The average roughness under stylus force of 7 mg is 0.91 μm for sample A, 2.54 μm for sample B, and 0.79 μm for sample C. The pore structure of coating layer was determined by mercury porosimetry. Figure 2 shows the pore size distribution curves of three samples. Note there are two peaks for sample A in the coating pore size range: one peak corresponds to those big pores and other one corresponds to small pores. Therefore, sample A has much more fine pores than other two samples. Compared to sample C, sample B is more porous and has more small pores.

Two inks (M1 and M2) provided by Sun Chemical were formulated with two resin levels. These inks are two of the three magenta inks used by Gros, *et al.* (2002) in their studies. Table 1 lists the pigment/resin ratio, ink tack, and the filtercake resistance. Ink M2 has a smaller filtercake resistance and sets more rapidly on the coated surface than ink M1.

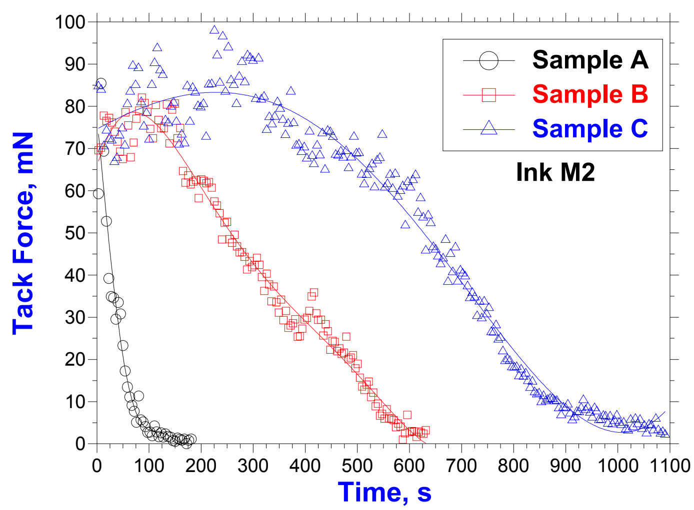
Ink tack dynamics of two inks on three paper samples were measured with the Micro-tack device (Xiang, *et al.* 1999) as shown in Figure 3. The difference in ink setting rates between the three paper samples and between the two inks can be seen. Ink gloss dynamics of ink M2 on three samples were also measured right after printing with a glossmeter mounted on a lab press (Glatter, *et al.* 1998) as shown in Figure 4. We see again that fast setting surface gives lower ink gloss than slow setting surface.

Table 1 Some properties of two inks used

Inks	Pigment/resin ratio	Tack (Inkometer)	Filtercake resistance (α), m/kg	Ink setting
M1	1.8	15.0	300	Slow
M2	1.3	13.6	65	Fast



a. Ink M1



b. Ink M2

Figure 3 Ink tack dynamics of two inks on three papers

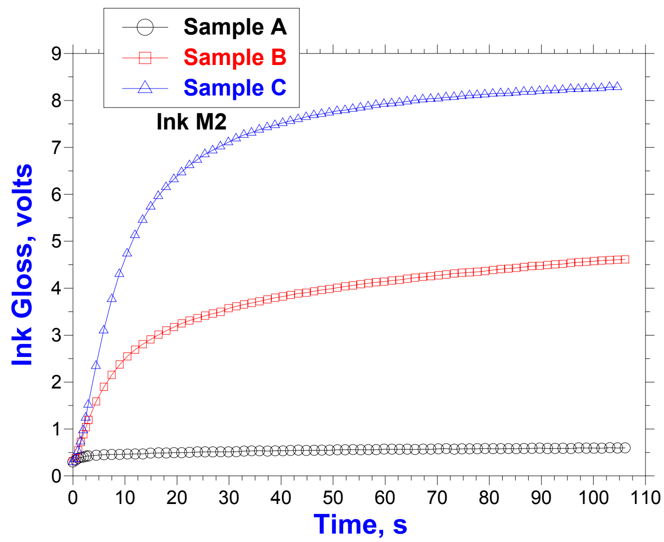


Figure 4 Ink gloss dynamics of ink M2 on three papers

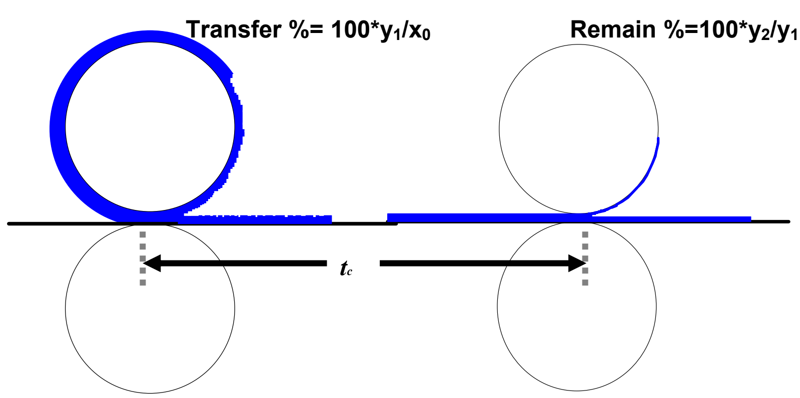


Figure 5 Ink transfer test on KRK lab press: t_0-nip time, t_c- time interval between units, nip load: 981N, printing speed: 1.0 m/s

Three samples were printed on a laboratory print tester (KRK) press. Figure 5 shows the procedure. Samples were printed with the first nip and went through a second nip. Ink transfer after the first and second nips were determined by weighing the two printing discs before and after printing. The time interval between two nips were adjusted to a wide range to examine the effect of ink setting rate on the ink reminding with the paper after second nip. The percent transferred in the first nip is the weight loss divided by the total initial ink weight. The percent remaining after the second nip is the amount final on the sample divided by the amount after the first nip.

Results and Discussions

Figures 6 and 7 show the percent ink transfer after the first nip and the second nip for the two inks on three coated samples at ink level of 0.3 mL and time interval of one second between two nips. For ink M1, a slow setting ink, the percent transfer is ranked as paper A with a fast setting coating layer, paper B with a medium setting coating layer, and paper C with a slow setting coating layer. For ink M2, a fast setting ink, paper A, gives a higher ink transfer than the other two papers. Interestingly, we see that paper C has even higher ink transfer than paper B. Two things might be possible to be considered for this different trend: 1) fast setting ink (M2) may reduce the effect of coating setting rate, and 2) surface smoothness of paper C is higher than paper B. The surface smoothness may play a dominant role in determining ink transfer in a single nip printing. The ink transfer results shown here seem to agree well with LePoutre and De Grâce (1978). They found that coating porosity and absorbency had little or no effect on ink transfer, print density in a single nip print test.

However, the percent of ink staying with the paper depends on the coating setting rate. The percent remaining after the second nip increases with coating setting rate for both inks. The fast setting ink M2 gives a higher ink transfer and a larger amount of ink on the paper after the second nip for papers A and C than ink M1, but not much difference on paper B. On the other hand, the results here also implies that we must be cautious with any single nip print test because it does not always give a correct trend to predict effect of coating setting rate on the print density in multiple color printing.

With increasing the ink level, a similar trend is noted as shown in Figures 8 and 9 for two inks on papers B and C. For ink M1, percent transfer is not much different between paper B and paper C. For ink M2, percent transfer is always higher on paper C than on paper B (Figure 9). Again, percent remaining after the second nip is higher on paper B than on paper C for all ranges of ink level tested for ink M1 and for the range of ink level less than 10 g/m^2 for ink M2. After the ink level is over 10 g/m^2 for ink M2, not much difference in percent remaining was noted between paper B and paper C. Figures 10 and 11 compare two inks on two papers. On paper C, ink M2 has a higher ink remaining than ink M1. On paper B, not much difference was noted between two inks. The effect of ink types on ink transfer/remain is reduced on this paper with a medium setting coating layer.

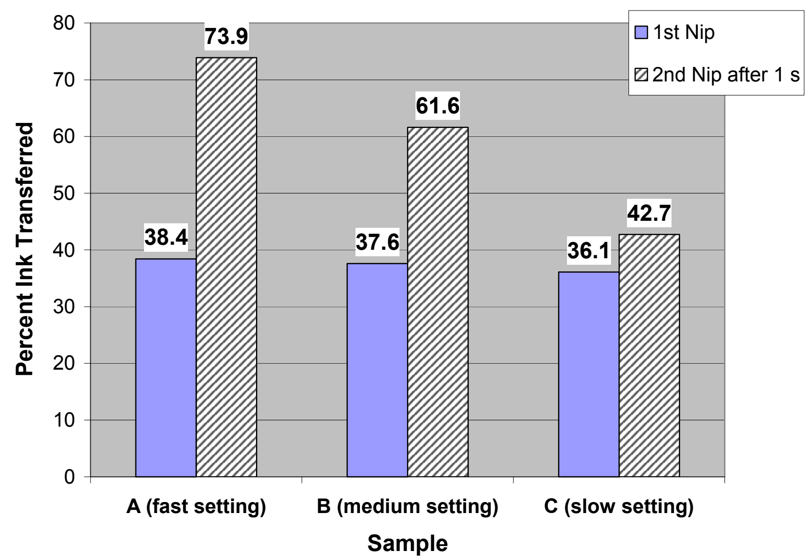


Figure 6 Percent ink transferred for ink M1

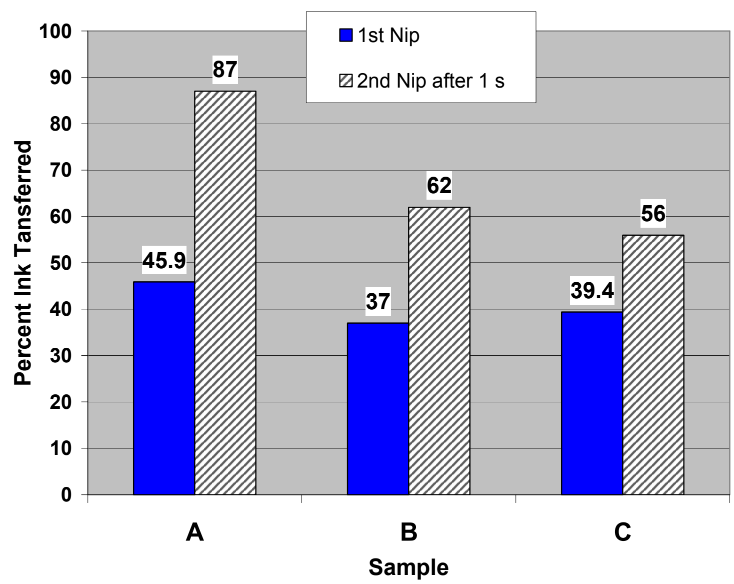


Figure 7 Percent ink transferred for ink M2

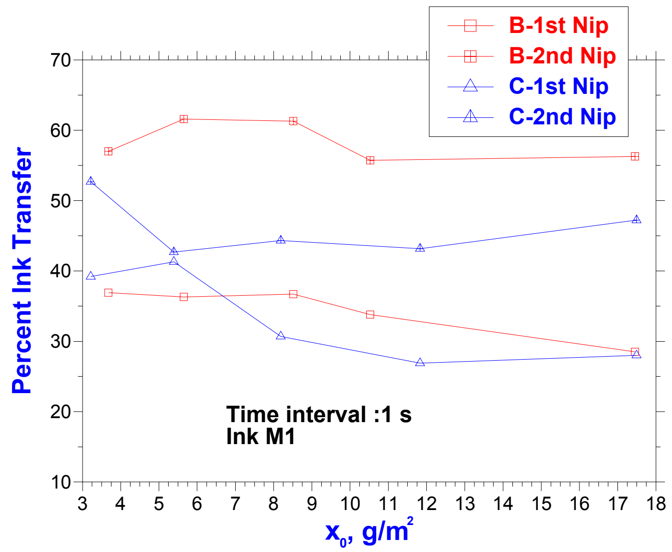


Figure 8 Percent transfer/ink remaining (%) as a function of ink level for ink M1 on paper B and paper C.

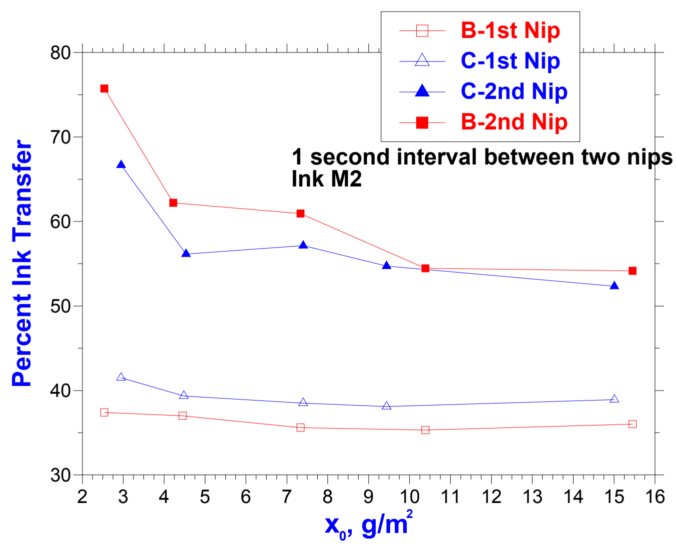


Figure 9 Ink transfer/ink remaining (%) as a function of ink level for ink M2 on paper B and paper C.

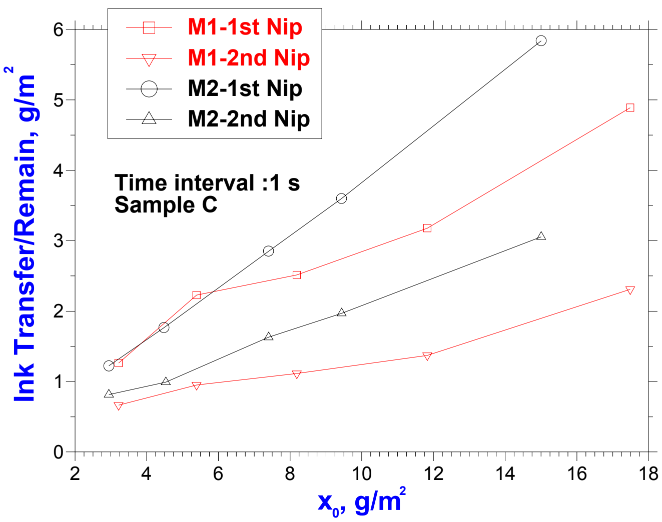


Figure 10 Ink transfer/ink remaining (g/m2) on paper C: ink M1 vs. ink M2

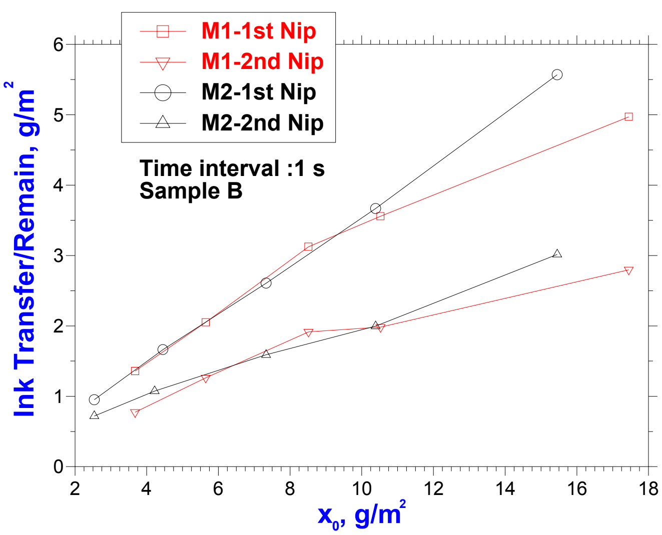


Figure 11 Ink transfer/ink remaining (g/m2) on paper B: ink M1 vs. ink M2

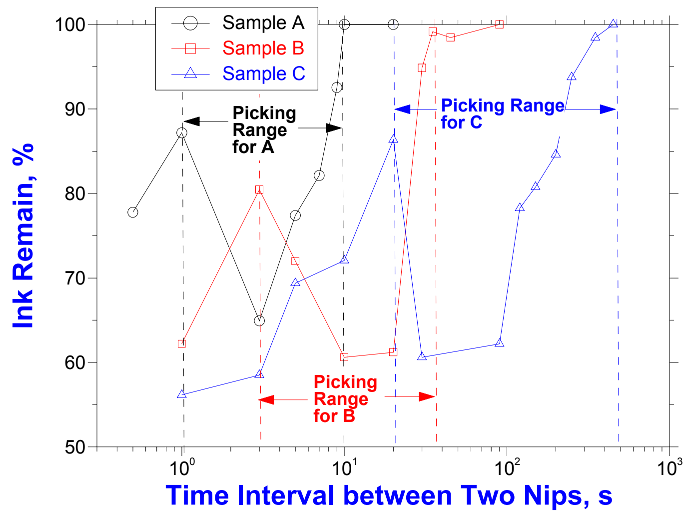


Figure 12 Ink remain (%) after 2nd nip as a function of time interval between two nips

By increasing the time interval between two nips, an increase in ink remaining is expected because that ink film filtercake formed on the paper surface becomes thicker and the free splitting ink layer becomes thinner and thinner. The ink remaining will reach a maximum level when whole ink layer is "dry" on the surface. Figure 12 shows the percent remaining of ink M2 on three papers. Instead of consistently increasing with time interval between nips, the percent increases before decreasing. At a longer time, the percent increases again until reaching an equilibrium level when no ink film is seen to re-transfer to the second disc. The delay time for the decrease and the time to reach the equilibrium decrease with the coating setting rate.

During the printing tests, a mottle-like pattern appeared when the time interval increases to certain level. A close look at those "mottled" print under an Environmental Scanning Electron Microscope (ESEM) indicates that it is not print mottle problem, but a small-scale picking phenomena in the second nip, as shown in Figure 13. Ink tack increases after printing in the first nip. Therefore, if there is an uneven distribution in either surface strength or non-uniform ink setting, picking may occur locally in the weak area or fast setting area. This small-scale picking gives an artificial decrease in the percent of ink remaining on the paper after the second nip. As shown in Figure 3, paper A with fast setting surface builds up ink tack more rapidly and therefore has a picking problem earlier than other two papers. For three papers, a maximum ink remain can be obtained without any picking problem if the time interval between two nips is long enough. As shown in Figure 12, this waiting time before second nip is about 10s, 90s, and 450s for papers A, B, and C, respectively.

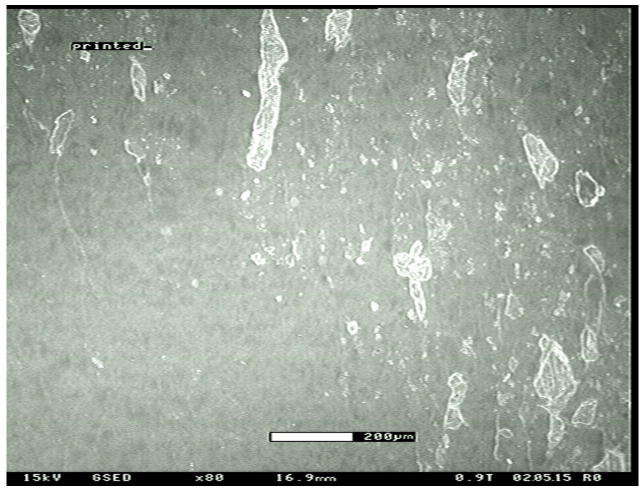


Figure 13 Micro-picking happens because of ink tack buildup (paper B)

Concluding Remark

From above results obtained, the conclusions can be summarized:

- Ink transfer onto the paper surface in the first nip is controlled by setting rate of coating layer, setting rate of ink, and surface smoothness. At similar surface smoothness level, a fast setting coating layer or a fast setting ink results in a higher ink transfer ratio.
- The ink remaining after second nip is determined by the setting rate of the setting rate variation induced coating layer. This effect can be reduced by using fast setting ink.
- Micro-picking may occur in second nip if coating layer sets ink too fast or coating layer is not strong enough. This is different from the backtrap mottle (BTM) even though they look similar to human eyes.

Acknowledgement

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