PRINTING TACK DEVELOPMENT AND COATED PAPER STRUCTURE

J.S. Aspler*, Y.-H. Zang, L. Larrondo, and L. Perron

Keywords: Absorption, Coated, Ink, Paper, Tack

Abstract: We define Printing Tack to be the ink tack in contact with paper in the printing nip. Time-dependent changes in printing tack depend on coating structure and composition. For very absorbent coatings, the printing tack starts from a maximum value, and decreases rapidly. For very non-absorbent coatings, the printing tack increases to a maximum and then slowly decreases. Penetration of the polymer solution phase causes the printing tack to *decrease*, since printing tack decreases as the "effective" ink film thickness decreases. Diffusion of the solvent into the coating binder may also cause tack to increase, since the concentration of polymers within the ink would increase. However, a quantitative explanation of these phenomena requires further study of ink-coating-press interactions, including the solution of the equations governing fluid flow through the coating pore structure and solvent diffusion through the coating binder.

Introduction

Tack is one of the most important physical properties of a printing ink, influencing (among other things) halftone dot structure on the plate and ink transfer to the paper. Incompatibility between the paper's surface strength and ink tack is also a notorious cause of surface-strength related problems, such as picking, delamination, and blanket piling. Normally, ink tack selection is a compromise between the high tack that is desirable for print quality, and the need to avoid surface strength problems related to excessive tack.

While knowing the initial ink tack is useful, tack is not constant during printing. In a heatset offset press, during the brief period (perhaps three - five seconds) between the first printing nip, subsequent printing nips, and the drying oven, the tack changes as the ink film consolidates. Furthermore, through the

---

*Pulp and Paper Research Institute of Canada, 570 St. John's Blvd., Pointe Claire, Quebec, Canada H9R 3J9. e-mail: aspler@paprican.ca

process of back-trapping, ink builds up on later printing blankets. The equilibrium tack on these later blankets is different from the original tack, and is almost certainly influenced (in a still poorly understood manner) by the fountain solution, by the other inks, and by the changes that occur during its passage through the press. However, a knowledge of how the tack of the fresh ink on the paper surface changes as the paper moves through the press is important in understanding questions such as surface strength and print quality requirements.

Even if the initial ink tack is compatible with the paper, excessive tack increases can still damage the paper surface later in the press. Uneven changes in ink tack can also lead to non-uniformity in print density and print gloss. Excessively absorbent coatings are more susceptible to piling, explained by the following, conventionally-accepted mechanism:

1. Immediately past the first or second colour units of the press, the fluid phase penetrates excessively, leaving a higher-tack ink film on the paper surface.
2. On later colour units (typically, the third or fourth), ink back-transfers from the paper to the blanket. If the ink tack has built up excessively between the first and later colour units, then the built-up layer on the blanket will be of excessive tack.
3. The high-tack ink layer builds up on the blanket, and increases even further in tack. Paper subsequently passing through this nip suffers surface damage due to contact with the high tack layer.

Swan [1] described a device that measures tack changes with time. "Tack" is obtained from the force required to pull a soft rubber roller away from an ink film on a paper strip. The paper and the roller advance between each measurement, about three seconds apart. Therefore, an untouched ink film is presented to the rubber roller for each measurement.

Using this device, the following, general shape of the tack development curve was found for all coatings: an initial, rapid buildup; a (possible) intermediate equilibrium tack region; followed by tack decay. Swan showed that excessively absorbent coatings gave more blanket piling, the result of an excessively-rapid tack buildup.

Gane [2] used the same device to examine the tendency of different coatings to give mottled prints. Differences in the rate of tack decay (on the scale of a few seconds) were related to mottling tendencies (slower decay in tack tending to give more mottle). Longer-term decay of tack (on the scale of many minutes) was related to problems such as ink adhesion and durability. Gane presented a conceptual model of tack development, in which the measured tack response is the sum of several simultaneous events. The increase in tack at short times (a few seconds) was attributed to the speed with which the ink penetrates the coating, with

a greater tack resulting from a greater microporosity plus wettability of the coating. The maximum separation force is in turn a measure of the adhesion between the ink and the coating surface, and the cohesion of the ink film itself.

Robie *et al.* [3] characterized different coated papers printed on a 4-colour sheetfed offset press. Commercial coated papers made under controlled conditions with very different absorption characteristics -- representing the range of North American production -- were printed together in the same press run. They concluded that ink absorptivity has a surprisingly small effect on the equilibrium print density. However, transient print density shifts (lasting for only a small number of impressions) were much greater when the printer switched from a paper with one coating formulation to a paper with a different coating formulation. Two samples from that report, with very high and very low ink absorptivity, were examined in the present work.

Van Gilder and Purfeerst [4] determined the rate of tack buildup for coatings formulated with different polymer binders. Low surface-energy polymers led to greater tack buildup and so to more tack-related problems, This drew upon early work by Kelly *et al.* [5], who showed that the greater the interaction between the ink solvent and the coating binder, the faster the ink setting. As we will show, the concept of ink solvent - coating binder interactions (that is, preferential wetting and sorption of ink solvent into different coating polymers) has been neglected, and may play a key role in ink setting and tack buildup on coated papers.

The objective of the current work is to examine the influence of coating structure on tack development in the printing nip, using direct measurements of printing tack. We have examined model coatings on Mylar, and commercial coated papers.

Direct Measurement of "Printing Tack" in the Printing Nip

Traditionally, printers and ink manufacturers have used devices such as the Inkometer to measure ink tack. The values derived from these instruments, while useful, are arbitrary, and are not related to fundamental ink properties.

For this reason, Zang *et al.* developed the "Printing Press Tackmeter" [6]. This allows us to directly measure the pressure profile of the ink film in the printing nip. Tack is defined from the maximum tensile stress exerted on the ink film as it splits in the printing nip (Figure 1). This definition of tack was suggested many years ago, based on calculations from lubrication theory, but direct measurements have only recently become possible. Aspler *et al.* [7] introduced the concept of "printing tack" to describe ink tack in contact with the paper in the printing nip. Using the Printing Press Tackmeter, Aspler and Taylor [8] measured the change in

tack with time of a water-based ink. Tack reaches a maximum, before dropping with the development of the dried, consolidated ink film.
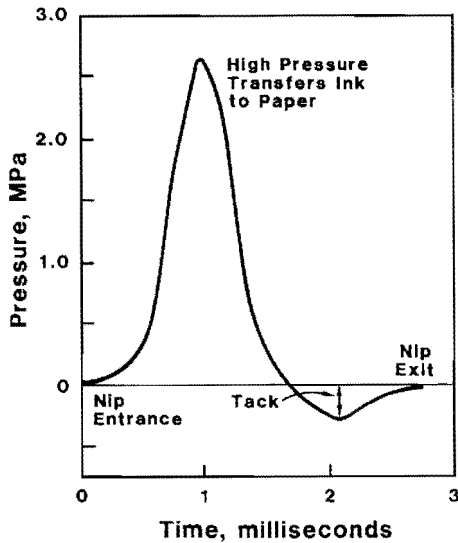

Figure 1. Typical pressure profile curve in the nip.

Experimental

Test Procedure

Measurements were done on Paprican's Printing Press Tackmeter, in which a pressure transducer is mounted in the printing cylinder of a laboratory rotary press, as described previously [6 - 8]. A schematic diagram is shown in Figure 2.

We kept to a strict timetable for each step in the process, to avoid inconsistencies in tack measurements that might result from solvent evaporation. The total time for ink distribution was four minutes:

1. Initial application of ink to the inking system: 15 s.
2. Application of ink to the plate: 45 s.
3. Weighing of the plate, installation over the pressure transducer in Figure 2, and transfer of ink from the plate to a Mylar film on the impression cylinder: 60 s.
4. Removal and re-weighing of the plate, transfer of ink from the impression cylinder back to the pressure transducer: 60 s.

5. Final weighing of the Mylar film, replacement of the Mylar film with the paper sample, to the start of the experiment: 60 s.
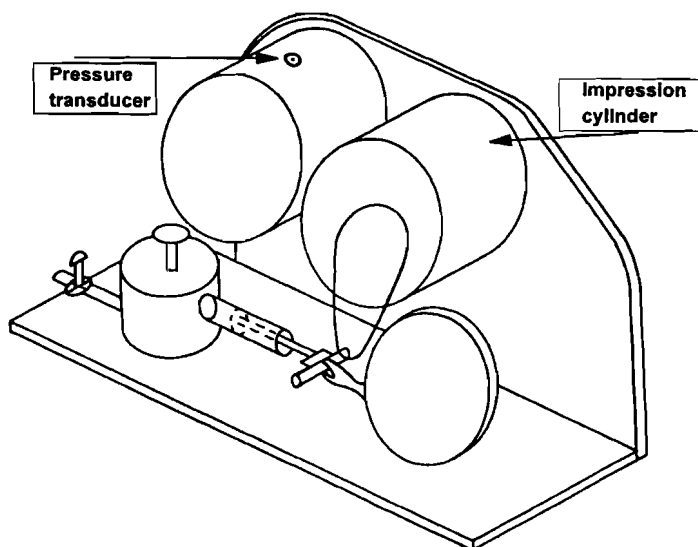

Figure 2. Schematic diagram of the Printing Press Tackmeter [6]. The pressure transducer is mounted in the plate cylinder. After the surface of the pressure transducer has been inked, the pressure profile is measured during the printing of the paper mounted on the impression cylinder.

Although solvent evaporation can never be eliminated, using this procedure, evaporation is at least kept constant in each experiment. We stress that, although the distribution time is four minutes, the start of the experiment is the point when the ink first contacts the coating. The amount of ink transferred is determined (in g/m^2) from the ink weight and the area of the plate.

Once the ink has been transferred and the paper mounted, the pressure profile is measured, with one reading every 10 μs. These data are exported to a computer and are converted to a pressure vs. time curve using a calibration program built into a spreadsheet.

The press can also take consecutive printing tack measurements over a short period, as described by Aspler and Taylor [8]. The press was run at the maximum speed, 5 m/s, with a set interval between impressions, from 1 s to 10 s. During the rapid acquisition of consecutive pressure profiles, we were limited by our computer's speed and memory to only 15 consecutive readings. Therefore, for each sample, the printing tack vs. time curves were obtained from separate experiments

on separate sheets of the same paper: 0 - 14 s (1 s between impressions), 0 - 42 s (3 s between impressions), 0 - 70 s (5 s between impressions), and 0 - 140 s (10 s between impressions.) This overlapping is shown in Figure 3, and is a possible source of error, especially for less uniform coatings. However, we felt that this was necessary, in order to obtain a wider range of experimental data.
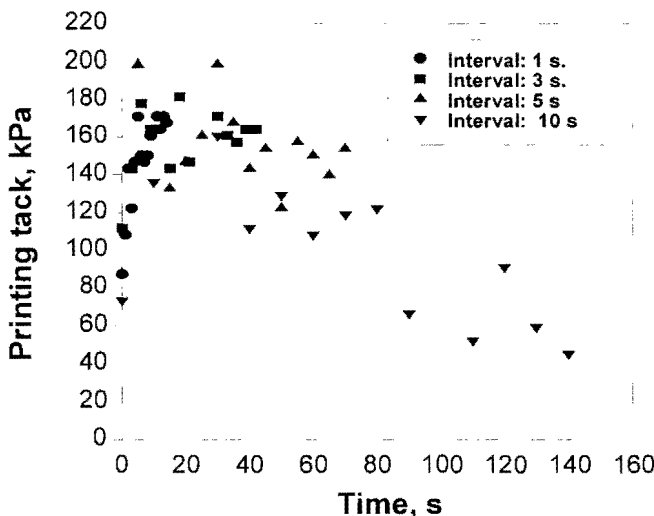
Figure 3. Printing tack development of heatset offset ink on woodfree paper WF-5. To obtain this graph, printing tack readings were taken at the intervals shown (1, 3, 5, and 10 s), and the resulting curves were overlapped.

For the control Mylar film, tack measurements were extended for about 20 minutes. For all the results reported here, the initial ink film thickness was maintained in the range 4.5 ± 0.3 g/m^2, or about 4.5 µm, in thickness.

Sources of Error

The choice of a transducer had been a compromise between the maximum sensitivity needed in the printing tack region, and the need to protect the transducer from excessive positive pressures before the nip centre. Scatter in the printing tack readings, while comprising only a small percentage of the maximum compression value, makes up a much greater percentage of the printing tack value. For example, scatter of ± 10 kPa makes up less than 1% of the absolute value of the pressure signal, but comprises up to $\pm 10\%$ of the printing tack region. Given our transducer, this was unavoidable.

Ink

A commercial heatset offset ink (Hostmann-Steinberg) was used. Some of its key properties are described in Table I. The evaporation rate of this ink was

measured, under both dynamic and static conditions. The ink film thickness was the same as that used in the rest of the study ($\approx$ 4.5 µm), and is within the range of commercial ink thicknesses. These evaporation curves are shown in Figure 4, and were used to estimate the amount of solvent lost by evaporation during printing on the actual coatings.

TABLE I
Properties of Heatset Offset Ink

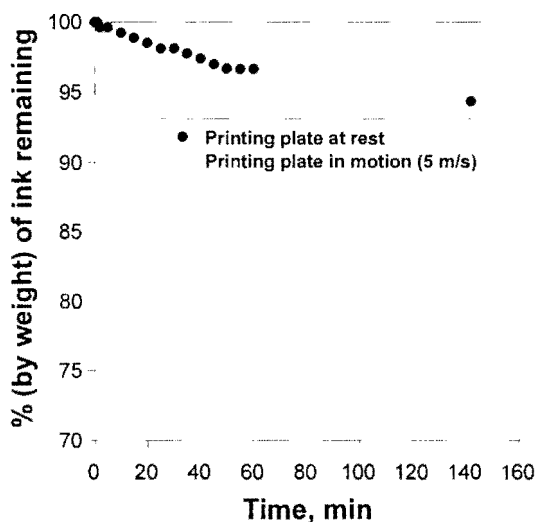| Component	Weight, %	Viscosity, Pa•s
Pigment (carbon black)	*17.5*	-----
Dissolved polymers and resins	*33.5*	*30*
Petroleum distillate (boiling range 243 °- 290 °C)	*35.5*	*≈ 0.004*
Vegetable oil (specific gravity = 0.935)	*10.0*	*≈ 0.040*
Low molecular weight ingredients (toner dye, antioxidant, etc.)	*3.5*	------

Figure 4. Evaporation with time of a heatset offset ink, under static and dynamic conditions.

Coated Papers

Two model coatings on Mylar™ film were used. The pigment was a commercial coating clay (Hydrafine, from J.M. Huber Co.), and the binder was a film-forming, carboxylated styrene-butadiene latex from BASF. These coatings have been described in detail previously [9]. The coatings were prepared by applying the coating colours to the Mylar with a drawdown bar, and were air-dried at room temperature. The coatings were not calendered. Void fractions (determined

168

by the oil penetration technique described by Lepoutre [10]) and ink absorbency index values (determined from Croda ink smear test [9]) are shown in Table II.

TABLE II
Void Fraction And Croda Ink Absorbency Index Of Model Mylar Coatings

	Latex content, pph	
	10	20
Void fraction, [10]	0.33	0.23
Croda ink absorbency index, % , [9]	70	60

Previously-characterized [3] coated freesheet samples were provided by S.D. Warren Co. These vary in the amount of binder (Table III), but the binder and pigment are the same. While the ink immobilization rate and the binder content are very different for these samples, they still represent the range of North American coated freesheets in their surface properties.

TABLE III
Woodfree Coated Samples Of Different Binder Content And Ink Penetration Rate [3]

Sample	Binder content, % by dry volume	Tappi gloss, %	Rate of ink immobilization, * g/cm s	Walker-Fetkso b parameter (ink immobilization), g/m^2	Coating void fraction (bulk coating)	Mean pore radius, μm (bulk coating)
WF-1	19	70.3	25	1.29	0.34	0.09
WF-5	37	66.6	2.5	0.39	0.31	0.08

* Rate of ink immobilization from Robie et al. [3]

Several commercial lightweight coated papers printed as part of a trial on a commercial heatset offset press at the Rochester Institute of Technology were also examined. These are described in Table IV. Samples LWC-10 and LWC-11 were made on the same paper machine and coater, from the same basestock. Only the coating formulations -- and so the surface properties of the coating -- were changed. Sample LWC-5 was made on the same machine, but with a different basestock and coating formulation.

TABLE IV
Properties Of Commercial Lightweight Coated Papers

Sample	Coating void fraction	Average coating pore radius, μm	Contact angle of linseed oil on coating, degrees	Tortuosity
LWC-5	0.29	0.07	63	0.97
LWC-7	0.22	0.12	52	1.02
LWC-9	0.29	0.10	39	1.38
LWC-10	0.34	0.08	50	1.29
LWC-11	0.35	0.07	60	0.77

Results

Printing Tack Development on Model Mylar Coatings

　　　　Figure 5 shows the printing tack curves for the heatset offset ink on Mylar film and on the model coatings. On Mylar (Figure 5a) there is a rapid increase in printing tack, followed by a long-term plateau. For the uncoated film, a possible reason for this short-term increase in tack is the loss of the most volatile portion of the ink solvent by evaporation. However, Figure 4 showed that, within 100 seconds, the amount of evaporation of ink solvent is minimal ($\approx$ 2%), and a quantitative explanation for the initial rise in printing tack is unclear.
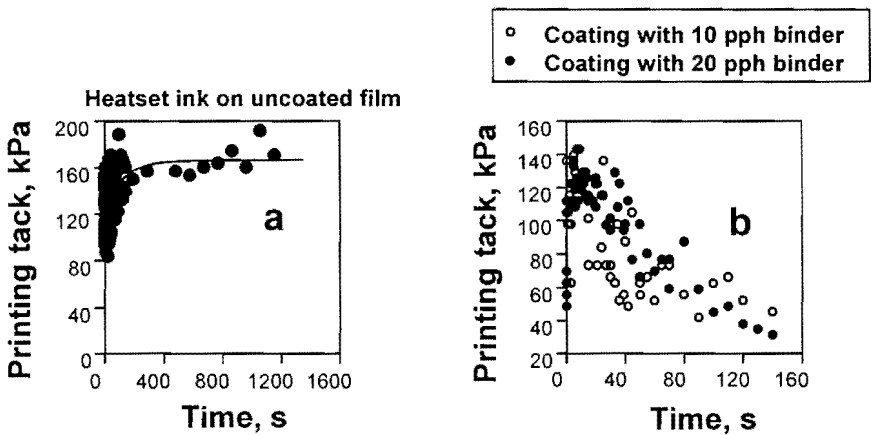

Figure 5. 5a: Printing tack development of heatset offset ink on Mylar film. The solid line through the uncoated Mylar film data represents an (empirical) fit to the equation:
$Tack = 41 \ (1 - e^{-0.0080t}) + 126$.
5b: Printing tack development on model coatings on Mylar film.

　　　　The maximum printing tack is greater on the uncoated Mylar ($\approx$ 180 kPa) than on the coated Mylars ($\approx$ 140 kPa). This is likely the result of the greater effective ink film thickness on the uncoated film, leading to a greater printing tack, as demonstrated previously [6].

As shown in Figure 5b, for the model coatings on Mylar, at short intervals (up to ≈ 15 s), the tack buildup was extremely rapid, and the different samples could not be distinguished. Past the maximum printing tack value, the difference between the two coated Mylar films shown in Figure 5b is significant*. At longer intervals, the printing tack decreased with time.

As the vehicle (solvent + dissolved polymers) penetrates, two events occur. The first is a relative increase in the pigment concentration. Increased pigment concentration, with the same amount of dissolved polymers in the vehicle, has little effect on printing tack [6].

However, as the vehicle phase (solvent + polymers) penetrates, the effective or "free" ink film thickness decreases, and so [6, 7] the printing tack decreases as well. As a more porous coating absorbs the vehicle more readily, the more porous sample (10 pph latex binder) showed the faster decay in tack, while the 20 pph coating showed a slower decay in tack.

Printing Tack Development on Wood-free Coated Papers

Figure 6 shows the buildup and decay of printing tack on the woodfree coated papers. Since these are particularly smooth coatings, the maximum printing tack values are higher than on the coated Mylar, and are comparable to the values found on the Mylar film (≈ 180 kPa).

On sample WF-1, printing tack buildup was so rapid that no rise time could be resolved. Rather, the printing tack decreased from a maximum value at the first impression, until the ink had consolidated. While extremely absorbent (rate of ink immobilization, Table III), Sample WF-1 is still representative of commercially-available coatings. Sample WF-5 was a particularly non-absorbent, but still conventional, coating. For this sample, the printing tack increased to a maximum and then decreased, until the ink film had solidified.

We note that despite the very large difference in binder content and ink absorbency, the porosity of these coatings as measured from the bulk content are very similar. Perhaps a measure of the *surface* porosity would be more appropriate, or perhaps only the binder content matters. We note again that, as with the model coatings on the Mylar film, these coatings differ in the amount, but not the type, of binder.
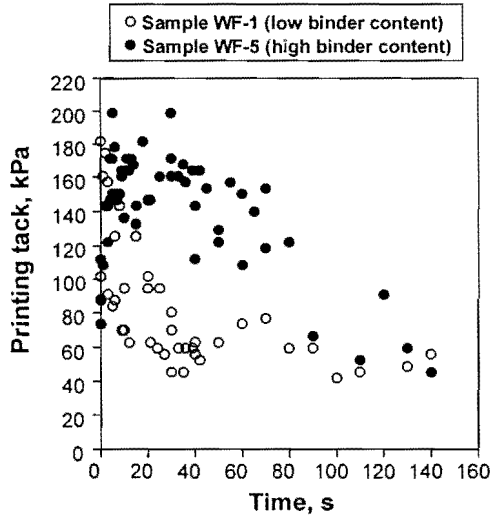
Figure 6. Printing tack development of heatset offset ink on woodfree coated samples.

Printing Tack Development on Commercial Lightweight Coated (Lwc) Papers

Figure 7 shows printing tack development on the five LWC samples. Much of the detailed information on the coating formulations is proprietary to the manufacturers.

For sample LWC-7, both printing tack buildup and tack decay are very slow. Sample LWC-11 showed the fastest printing tack buildup and decay. Results from these two samples are plotted together (Figure 7a), and show the range of values possible in printing tack development

Samples LWC-10 and LWC-11 (Figure 7b) were made with the same basesheet, and differ only in coating formulation. The difference between these samples is statistically significant. As shown in Figure 7b, Sample LWC-10 has a slower printing tack decay than does sample LWC-11. Sample LWC-10 is slightly less porous, which would give slower absorption, but also has a lower contact angle with linseed oil, which would give faster absorption. To explain the observed difference, we need to consider another mechanism, solvent diffusion, which will be discussed later.
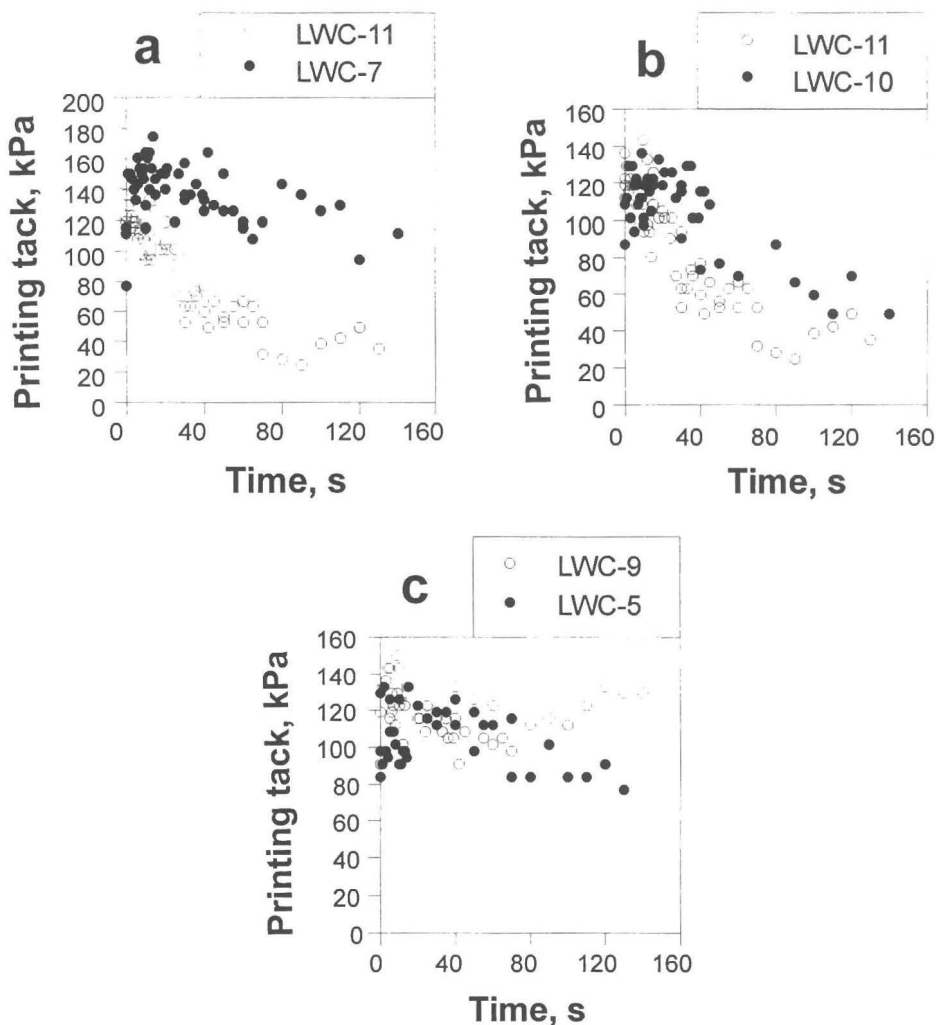
172

Figure 7. Printing tack development of heatset offset ink on lightweight coated samples. 7a: Samples LWC-11 and LWC-7; 7b: Samples LWC-11 and LWC-10; 7c: Samples LWC-9 and LWC-5.

As shown in Figure 7c, the printing tack decay for LWC-5 is significantly faster than the decay for sample LWC-9 at longer contact times. The pore fractions of these two coatings are virtually the same (Table IV). Moreover, the contact angle for linseed oil on LWC-9 is much less, which should make it more ink-absorbent, not less. However, a larger average pore size for sample LWC-9 with the same void fraction means that the inter-pore connections are smaller. This leads to a greater

tortuosity for sample LWC-9 (Table IV), which then may lead to slower fluid absorption. All of these measurements were taken with the same ink. A quantitative estimate of these effects is the subject for our future study.

Discussion

The Mechanism of Printing Tack Development

As shown in Figures 5–7, no unique curve can describe printing tack development of a single ink on different papers. Instead, different papers have different characteristic curves, depending on both their physical and chemical structures.

Several events contribute concurrently to changes in printing tack during ink setting. During the drying of inks and other coatings, both tack and viscosity increase as the film consolidates. As ink solidification nears completion, the tack of the ink approaches zero*.

It is well-established [4, 11] that a phase separation occurs at the coating-ink surface. As the liquid phase (ink "varnish" or polymer solution) penetrates the coating, a filter cake of ink pigment remains behind at the coating surface. The more the ink solvent interacts with the coating, the faster the ink consolidation, and so the faster the tack decay [4, 5].

1. Evaporation of Ink Solvent

From Figure 4 we see that only a small amount of solvent (< 2%) is lost by evaporation on the time scale of this experiment.Therefore, this invalidates the conventional wisdom that solvent evaporation contributes to tack buildup. Currently, there is no consistent, quantitative explanation for the observed behaviour.

2. Solvent Diffusion or Adsorption into the Polymer Binder

As found previously [4,5], the interaction between ink solvents and coating polymers is a factor in ink penetration, Let us assume that the polymer binder acts as a uniform film. Solvent diffusion into the binder would cause printing tack to increase at first as the polymer concentration increases, at least until the CPVC.

---

*The Critical Pigment Volume Concentration (CPVC) likely marks the point of maximum ink tack, in common with tack buildup of paints, adhesives and related liquids. However, a study of the CPVC is beyond the scope of this report.

The potential importance of this step was shown by Glatter [12], who modelled solvent diffusion into a polymer film, and the changes that occur in the viscosity of the ink film that remains behind. He predicted an extremely rapid viscosity increase in the remaining ink film: three orders of magnitude in less than one second. This rapid viscosity increase may be accompanied by a rapid increase in tack, as well as by a rapid drop in the rate of penetration.

Although diffusion coefficients have not been measured for these ink solvents and coating binders, we can make the following speculations, based on the literature and on classical polymer chemistry:

2.1   The diffusion coefficient is much greater for a solvent that interacts with a polymer film than for a non-interacting solvent. This helps to explain, for example, why previous workers have found faster ink setting on coatings made with polymers that interacted more strongly with the ink solvent.

In Figure 6 and Table III, the average void fraction and pore size (from bulk measurements, rather than from surface measurements) for the two woodfree coated papers are similar. Nevertheless, printing tack development and decay are much slower for sample WF-5, which contains twice as much binder as sample WF-1. Solvent diffusion is much slower through a film that is twice as thick.

2.2   The diffusion coefficients for hydrocarbon solvents through hydrocarbon polymers are greater -- by up to several orders of magnitude -- than their diffusion coefficients through cellulosic polymers [13]. In Figure 7b, the coating for sample LWC-10 contained both starch and latex. The coating for sample LWC-11 contained only latex. It is possible that the adsorption and diffusion of ink solvent are faster in sample LWC-11, while the starch in sample LWC-10 slowed solvent adsorption and diffusion. This question can only be answered by measurement of diffusion coefficients for the ink solvents and coating binders. Although this mechanism seems to explain some of the coated paper results, it still does not explain a very rapid increase in tack, as seen in the uncoated Mylar film (Figure 5), where solvent diffusion may be very slow. Further study is required to consistently explain the initial rise in tack.

3.   *Ink Varnish Penetration into the Coating*

The Lucas-Washburn equation is often used to model ink and fluid penetration into paper. Several authors have criticized the use of the Lucas-Washburn equation. One of the present authors has summarized these objections [11, 14].

The fundamental problem is that the Lucas-Washburn equation assumes the existence of an "infinite" reservoir of liquid. However, the initial ink film thickness

175

is only 4.5 μm, of which only about 2/3 is liquid phase. Calculations using reasonable values for the parameters in the Lucas-Washburn equation overestimate the rate of liquid penetration into the coating, by at least one order of magnitude. On our time scale, the Lucas-Washburn equation predicts penetration of a fluid layer several times greater than the total ink film thickness!

Therefore, even if there is a rapid initial penetration of the ink solvent into the coating, driven by capillary force, the penetration must be slowed very rapidly, providing further confirmation for the formation of a high viscosity filter cake layer. In Figures 5 - 7, penetration of the polymer solution phase causes the printing tack to *decrease*, since, as found previously [6, 7], printing tack decreases as the effective "free" ink film thickness decreases.

Conclusions

Different coatings allow ink to penetrate at different rates, leading to major differences in the development or decay of printing tack. The most absorbent lightweight coated sample described in this work, with the fastest printing tack decay, was also subject to delamination on a commercial printing press. Here, the paper contained less binder, and so had poorer surface strength.

However, there are advantages to such a coating: for example, when the printer is applying an extra-heavy ink coverage, and wants rapid setting. This very absorbent sample also had very good printability.

On the other hand, a particularly non-absorbent coating will often have excellent surface strength, but the printer may then be faced with problems related to poor ink transfer and slow ink setting.

We have provided further evidence for the fact that ink-coating interactions are not simply governed by the physical porosity of the coating, but are also governed by the nature of the ink solvent - coating polymer interactions. A quantitative analysis requires the solution of the equations governing fluid flow through the pore structure and solvent diffusion through the polymer binder. However, we have shown that the influence of coating structure on ink penetration and printing tack changes is quantifiable.

Acknowledgements

Literature Cited

1.   A. Swan, *The Problems of Ink Piling on Offset Litho Presses*, ECC International, St. Austell, Cornwall, England, 1990.

2.   Gane, P.A.C., Seyler, E.N., and Swan, A., *Some Novel Aspects of Ink/paper Interaction in Offset Printing*, Proceedings of the 1994 International Printing and Graphic Arts Conference, CPPA, Montreal 209.

3.   Robie, S.P., Niles, C.D., and White, D.E., *The Impact of Ink-coated Paper Interactivity on Density in Offset Printing*, Proceedings of the 1992 International Printing and Graphic Arts Conference, Tappi Press, Atlanta, 1.

4.   Van Gilder, R.L., and Purfeest, R.D., *Commercial Six-color Press Runnability and the Rate of Ink-tack Build as Related to the Latex Polymer Solubility Parameter*, Proceedings of the 1994 Tappi Coating Conference, Tappi Press, Atlanta, 229.

5.   Kelly, J.M., Russell, P.J., and Graham, F.H., *Result of an Investigation into Ink Setting Behavior on Coated Papers*, Proceedings of the 14th EUCEPA Conference, Budapest, 1971; paper no. 28.

6.   Zang, Y.H., Aspler, J.S., Boluk, Y., and De Grâce, J.H., *Direct Measurement of Tensile Stress ('tack') in Thin Ink Films*, J. Rheology, 35(3), 345 (1991).

7.   Aspler, J.S., Maine, C., De Grâce, J.H., Zang, Y.H., and Taylor, S., *Printing Tack, Part I: Influence of Paper Structure on Ink 'tack' Measured in a Printing Nip*, Adv. Printing Sci. and Technol., 22, 139 (1994).

8.   Aspler, J.S., and Taylor, S., *Tack Development in Water-based Inks*, Nordic Pulp and Paper Research J., 6, 4 (1991).

9.   Zang, Y.H., and Aspler, J.S., *The Influence of SB Latex on the Ink Receptivity and Print Gloss Development of Model Clay Coatings*, Tappi J., 78(1), 147 (1995).

10.   Lepoutre, P., *Liquid Absorbency and Coating Porosity*, Paper Technol. Ind., 19(9), 298 (1978).

11.   Aspler, J.S., and Lepoutre, P., *Transfer and Setting of Inks on Coated Paper*, Progress in Organic Coatings, 19(4), 333 (1991).

12.   Glatter, T., M. Eng. Thesis, University of Maine, 1996.

13.   Brandrup, J., and Immergut, E.H., ed., *Polumer Handbook,* second edition, J. Wiley & sons, New York, 1975, p. III-239.

14.   Aspler, J.S., *Interactions of Ink and Water With the Paper Surface in Printing: A Review,* Nordic Pulp and Paper Research J., (1), 68(1993).