Influence of topcoat pigment particle size distribution on tail-edge pick resistance in sheet-fed offset printing

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ABSTRACT: This paper describes ground calcium carbonate pigment particle size distribution and its influence on the tail-edge picking of pilot-coated paper as determined in full-scale sheet-fed offset printing. A tailor-made method was developed using a modified printing plate and high-tack inks to assess surface strength in terms of edge picking. In addition to the type, fineness, and particle size distribution of the ground calcium carbonate pigment, we also evaluated the solids content of the coating color, binder level, clay usage, and calendering. The printing test method provided differentiation relative to the investigated parameters, and it was possible to correlate these results with laboratory test data on ink-coating interaction and mercury intrusion porosimetry. Maximizing the solids content of the formulation to some extent compensated for the loss of pick resistance that followed binder reduction. Other laboratory tests showed poor correlation with the observed degree of edge picking.

Application: Pigment particle size distribution is best evaluated by applying test methods where the ink-coating interaction is determined as a function of time. Product development engineers will gain additional insights into the formulation changes necessary to avoid picking.

Coated wood-free (WF) papers are normally printed in sheet-fed offset (SFO) or heat-set web offset (HSWO) printing presses. Both processes involve the use of high-tack inks; in general, HSWO inks have lower tack than the SFO inks. In contrast to the HSWO process, where the web goes through a drying section, SFO printing is performed without externally applied heat. Ink drying in SFO takes place in two phases: first, ink is set off on the paper and then oxidative drying follows.

Usually, SFO is referred to as the most demanding printing process. Printing takes place at high speeds with multiple consecutive applications of ink and fountain solutions. The coating must withstand the splitting forces of the tacky inks several times in the presence of the aqueous fountain solution. Ink that sets too rapidly may lead to picking of the coating layer and subsequent contamination and runnability limitations in the print press, or may not meet the customer's print quality needs. In some instances, the paper may delaminate due to very high splitting forces.

Coating cost reduction is currently the top priority of coated WF paper producers. In the coating process, pigments and binders must be chosen to obtain the optimal balance of cost and quality. Latex binder is normally the most influential component of the coating cost; therefore, optimizing the latex level to a minimum provides a substantial opportunity for cost savings. To meet the increasing cost saving demands from their customers, latex suppliers have successfully developed high-strength latexes, which can reduce the addition level by 10%–20% compared to traditional latexes [1-3]. The high-performance latexes are more costly but still provide a cost benefit via the lower addition level and have become standard latexes, especially for SFO grades.

Nevertheless, replacing synthetic latex with starch-based binders (e.g., dextrinated starch) including biolatex is being considered, predominantly in precoats but also in the top coat or in single coating applications [4]. The driving forces for this substitution are mainly economical, but environmental aspects (carbon footprint) are playing a larger role. The binder choice and level not only influence the surface strength in SFO printing; they are also crucial for print quality and other important properties, such as fold cracking and glueability.

Ink setting characteristics of the coated surface influence the tack development of the printing ink and, therefore, to a great extent determine the demand for printing surface strength. The high-speed ink setting process is generally explained by assuming that the mechanism behind oil absorption can be described by the pore structure and chemistry of the coating. The theory of capillary forces controlling the loss of ink vehicle from the coated surface is broadly accepted. The relationships between coating pore structure, latex chemistry, ink setting, ink tack development, and print gloss have been reported in several publications [3,5-12].

Recent studies have introduced a mechanism for the ink vehicle distribution within the coating layer [13-17]. A high number of small interparticle voids (pores) in the coating results in a structure exhibiting a high capillary force. This is especially applicable for isometric particles because of the interconnectivity of the pores and their low aspect ratio, which promotes inertial wetting at the absorption front.

This kind of coating structure is typically produced by ultrafine pigments that are mainly blocky in shape, such as ground calcium carbonate (GCC) and fine U.S. glossing clay, with high specific surface area. Large pores in the coating consequently create a lower capillary pressure, meaning low initial ink setting rates and slow tack buildup of the printing ink. Larger pores also encourage penetration of the ink due to increased permeability. In general, a coating layer with fine pigments will result in a higher number of fine pores and faster ink setting, whereas coarse pigments will lead to a lower number of larger pores and slower ink setting [18].

It has previously been shown that latex modification can significantly influence ink tack development and coating pick tendency in the print press through particle size, solubility parameters, and molecular architecture [1,2]. The focus of the present study is on pigment variations and their effect on pore structure, ink setting characteristics, and tail-edge pick in SFO printing.

EXPERIMENTAL

Pilot coating

Pilot coater trials were performed with the objective of producing double coated papers with a range of different surface characteristics, thus providing a varying degree of edge picking in the SFO print trials. Topcoats were applied on a mill-precoated WF base paper. **Table I** provides a summary of the trial points (TP). Four commercially available GCC pigments, including one with narrow particle size distribution (NPSD) and one high-glossing clay, were part of the trial program.

Two binder levels were evaluated using a unimodal styrene-butadiene latex (Styronal D 628, BASF; Ludwigshafen, Germany) with a particle size of 140 nm and a minimum film-forming temperature of approximately 10°C. The fairly low binder level of 7.5 parts was chosen to reflect the ambitious targets of today's coated paper producers in optimizing the cost-performance relationship of their formulations. Reducing the amount of latex to 5 parts provided the means to effectively evaluate the impact of the binder on the surface strength in commercial printing and on the associated surface properties resulting in laboratory testing. Synthetic thickener was

	1	2	3	4	5	6	7	8	9	10	11
GCC 95 (80 % < 1 µm)	100	100	100	100	100	100	50				
Clay (high glossing)							50	100			
NPSD GCC (75 % < 1 µm)									100		
GCC 60 (60 % < 2 µm)										100	
GCC 90 (90 % < 2 µm)											100
Latex SBR	7.5	7.5	7.5	5.0	5.0	5.0	7.5	7.5	7.5	7.5	7.5
Synthetic thickener	0.10	0.15	0.20	0.10	0.15	0.20	0.25	0.15	0.15	0.30	0.20
Solids content	71	68	65	71	68	65	65	65	68	68	68

I. Trial program (topcoats).

added to obtain similar Brookfield viscosity (about 1000 mPa·s at 100 rpm) in all trial points.

The following pilot coating conditions were used:

- Mill blade-precoated base paper 78 g/m²
- Machine speed 1200 m/min
- Jet application, stiff blade
- Brookfield viscosity (100 rpm) 1000 mPa·s
- Coat weight 12 g/m²/side
- Supercalendering (11 nips, 300 m/min, 80°C, 120 kN/m)

The following were the evaluated parameters:

- Pigment type (GCC/clay)
- Pigment fineness (GCC)
- Pigment particle size distribution (GCC)
- Binder level
- Solids content
- Calendered vs. uncalendered

Calendering conditions were adjusted to obtain a sheet gloss of 75% for TP 1 and the same calender conditions were used for the remaining TPs.

Commercial printing trial method

An iterative process involving both pilot coater and print trials was followed to develop a sheet-fed print form that was especially prone to tail-edge picking—a printing defect that typically occurs at the interface of printed and unprinted areas. This modified print form was used in the subsequent trial work on which this paper is based.

A commercial market paper (glossy double-coated 115 g/m² paper from the same paper mill as the precoated paper used in the pilot coating trials) was identified as a suitable reference paper. The printing trials took place on a Manroland R706 LTTLV (L = varnish, T = drying section, V = stretched delivery section; Manroland, Chicago, IL, USA) printing press at a speed of 8000 sheets per hour. Six printing units (inks were identified as K, C No. 1, M, Y, C No. 2, and a blue-shade ink called Omya blue) and one varnishing unit were used. The first four inks were of especially high tack (ink tack 9.5–11 compared to 7.5–10 for standard inks), applied to further provoke differences between TPs in terms of edge picking. After the six printing units, the sheets were run through the varnishing unit (without varnish) to put additional stress on the printed surface.

The developed method puts high demand on surface strength in terms of tail-edge picking. This made it possible to run the trials at a relatively moderate printing speed compared to current standards, thus allowing enough time to obtain stable press conditions for each TP. The TPs were assessed by visually examining the degree of edge picking of the printed image and sweeping the rubber blanket at each printing unit by hand to estimate the level of blanket contamination. On the basis of this information, the degree of edge picking for the different trial points was divided into five categories

(I–V) on a scale between 0 and 100. The printing conditions were adjusted so that the reference paper showed a medium level of edge picking (around 50 on the scale).

The following are the five categories:

I: Picking on sheet visible to the naked eye; picking on several rubber blankets—clearly visible and well detectable by hand ⇨ unacceptable situation, paper replacement imperative

II: Picking on sheet visible to expert eye or with a magnifying glass; picking on several rubber blankets—clearly visible and well detectable by hand ⇨ extra cleaning intervals and therefore longer make-ready time and less production time

III: Picking on sheet visible with a magnifying glass; slight picking on more than one rubber blanket—visible and detectable by hand ⇨ extra cleaning intervals and therefore longer make-ready time

IV: No picking on sheet visible; minor picking on any rubber blanket—hardly visible, but detectable by hand ⇨ potential problem in achieving print runs of high quantity

V: No picking on sheet visible; picking on rubber blankets neither visible nor detectable by hand ⇨ no problem for the printer

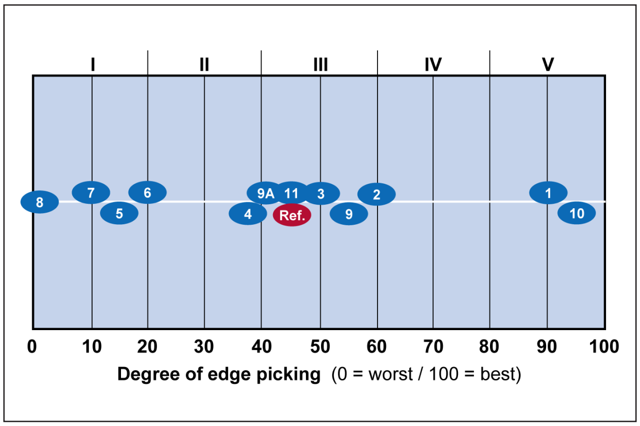
Laboratory test methods

Dry pick and wet pick resistance were evaluated on a Prüfbau printability tester, using the picking test ink 408002 (Nr. 2, Michael Huber; Munich, Germany) at an application pressure of 150 N/cm. In the dry pick test, a continuously increasing printing speed from 0 to 3 m/s was applied. For the wet pick test, the printing speed was increased in steps of 0.5 m/s up to 4.0 m/s, and the time interval between wetting and printing was 1 s.

Ink setoff was determined on an IGT A1 printability tester at a printing speed of 0.5 m/s, using a pressure of 200 N/cm at both the print unit and the counter print unit. Absorption test ink 52 0068 (Michael Huber) was used and the counter print was set off to a 150 g/m^2 WF paper. The counter times were 15, 30, 60, 120, 300, and 600 s. The optical density at 60 s is reported in this paper.

Two types of equipment were used to determine the rate of ink tack development recorded as a function of time; the Paper and Ink Stability Test (P&I Test, Nancy Plowman Associates; Burlington, MA, USA) and the Deltack (Prüfbau; Peissenberg, Germany). In the P&I Test, a standard "fast setting" cyan ink was used. From the resulting curve, the rate of tack development was obtained from calculating the slope. In the Deltack test, the heat-set printing ink 408020 (Michael Huber) was used.

Data on pore size distribution were obtained by applying mercury intrusion measurements (Autopore III mercury porosimeter, Micrometrics; Aachen, Germany). The maximum applied pressure of mercury was 414 MPa, which corresponded to a Laplace throat diameter of 0.004 µm. An equilibration time of 60 s was used for each of the increasing applied pressures of mercury. Pore-Comp software (University of Plymouth; Plymouth, UK) was used for correcting the mercury intrusion measurements with respect to the compression of mercury, expansion of the penetrometer, and compressibility of the sample.



1. Ranking according to degree of edge picking.

RESULTS AND DISCUSSION

Edge picking in commercial printing

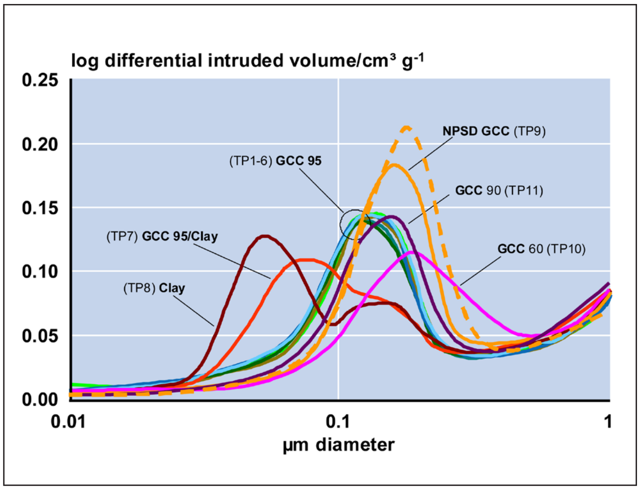
Figure 1 shows the ranking of the TPs within the five categories based on the degree of edge picking, where 0 represents the worst result and 100 the best. The GCC 95 (fine GCC) with 7.5 parts latex and maximum solids (TP 1) and the coarsest GCC 60 (TP 10) differentiated from the rest by showing the lowest degree of edge picking, whereas the 100% clay formulation (TP 8) yielded the worst results. The second-highest degree of edge picking was observed with the 50/50 GCC/clay formulation (TP 7).

Reducing the binder to 5 parts combined with reducing the solids content also gave rise to a significant increase in the degree of edge picking (TP 5 and TP 6). The rest of the TPs formed an intermediate group in which GCC 95 with 7.5 parts latex and medium solids (TP 2) and the NPSD GCC (TP 9) yielded the best results. TP 9A was the uncalendered version of TP 9.

Pore size distribution

Figure 2 shows the coating pore size distribution curves of the samples. The results confirm that coating pore structure largely is a function of pigment fineness; the finer the pigment particles, the smaller the pores. Similar results have been reported by Rousu [8]. With 100 parts fine clay (TP 8) a bimodal pore structure was observed, with peaks at 0.06 µm and 0.14 µm. The clay/GCC 95 blend (TP 7) had a major peak at 0.09 µm. While the distribution for the clay/GCC blend was almost monomodal, a light step in the curve was still noticeable at 0.14 µm.

The GCC 95 trial points (TP 1–TP 6) peaked around 0.12 µm. The minor differences when comparing TP 1–TP 3 and TP 4–TP 6 indicated that the overall pore structure was largely independent of variations in the solids content or the bind-



2. Pore size distribution, calendered (including TP 9A uncalendered—dashed line).

er level. Ström and Karathanasis [9] reported reductions in pore size with increasing amounts of latex, albeit at higher levels of binder addition. When calculating the mean pore radius (R_{50}), they observed a reduction only when the latex content reached 14 parts and higher. For the all-synthetic formulations used in the current study, the sealing effect of the binder at 5 and 7.5 parts was probably not sufficient to be reflected in the pore size distribution.

The critical binder volume fraction, i.e., the point when the latex totally covers the pigment particles, corresponded to a latex level of 24–27 parts [9,10]. Thus, at latex levels of around 10 parts, a current common level in the U.S. industry, there is not enough binder to cover the pigment particles efficiently. At 7.5 and 5 parts latex, the extent of complete pigment surface coverage by latex is even less evident and has no detectable influence on the pore size distribution. The results of Larsson et al. [19] support this statement, implying that the reduction in pore volume at these very low latex levels would be virtually negligible.

For TP 9 and TP 11, the NPSD GCC and the GCC 90 respectively, the peaks fell above 0.14 µm. The NPSD GCC, which was known to produce a coating with high bulk, accordingly gave a narrow distribution with a large volume contribution. The coarsest pigment, GCC 60 (TP 10), resulted in a broad distribution with a low peak at about 0.20 µm.

The effect of calendering on pore size distribution is shown in Fig. 2 for TP 9 versus TP 9A (TP 9A is the uncalendered version of TP 9, represented by the dashed line). Calendering made the surface smoother by aligning the pigment particles and melt flowing deformation of the latex binder, thereby resulting in a densification of the coating layer and a decreased pore volume. Even though the results showed that calendering shifted the pore size distribution toward smaller values, this effect was relatively small compared to the influence of pigment fineness/type. Furthermore, a larger effect on the pore size distribution was seen for the clay-containing coatings than for the pure GCC coatings because they are anisometric platy particles and alignment had an effect.

Suontausta [20] found that the calendering pressure reduced the porosity when the coating was based on platy clay particles, while the porosity of GCC-based coatings (having 12 parts latex) was affected only when high-temperature calendering was applied. The reduction in porosity as a result of high-temperature calendering can mainly be related to deformation of the latex binder within the coating matrix [19,20].

With 7.5 parts latex, it can be assumed that the temperature effect was rather limited and that calendering mainly resulted in a rearrangement of the particles. The resulting higher smoothness distributed the tack forces over a larger area and thus could be expected to show better pick resistance than a rougher uncalendered surface on which the load concentrated over a smaller area (TP 9 versus TP 9A in Fig. 2).

Ink setting

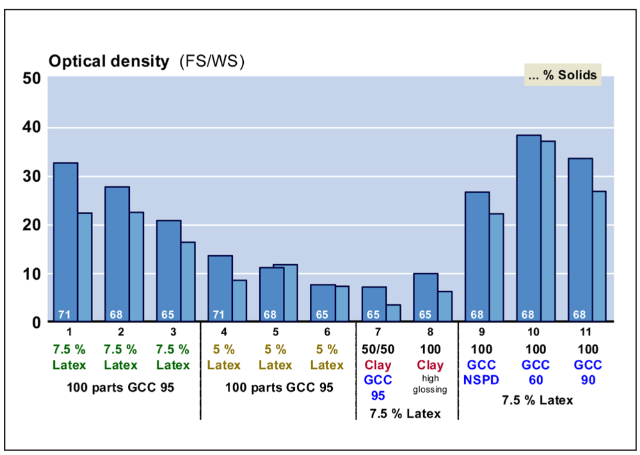
Figure 3 illustrates the ink-setting behavior as determined by ink setoff measurements. The results indicate that the following factors contributed to slower ink setting (smaller slope values):

- Using GCC instead of high-glossing clay
- Coarser pigments
- Higher solids content
- Higher amounts of latex

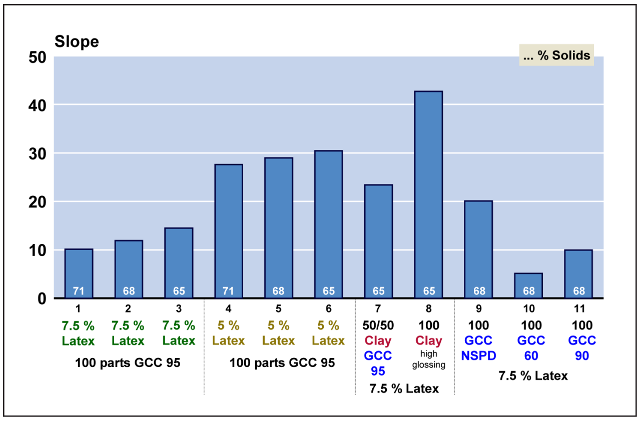
The NPSD GCC had a limited effect on edge picking or ink setting. The lack of fines in this GCC could be expected to affect the pore structure in such a way that ink setting would be slower than that of GCC 95 [3]. However, except for the finest particles, the overall fineness of the GCC 95 and the NPSD GCC were comparable [5], which would support the similar ink-coating interactions of these two pigments.

Ink tack

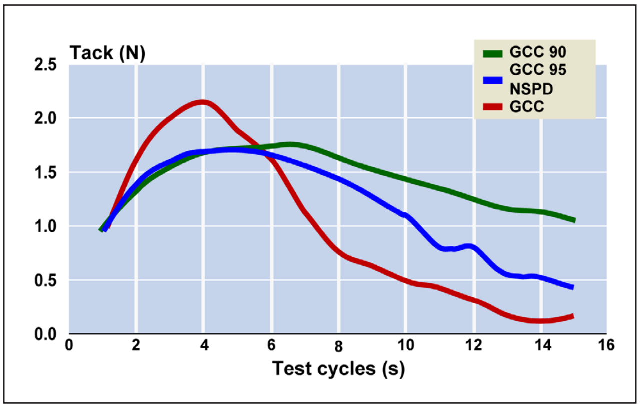
Surface strength in the sheet-fed offset process is primarily related to the ink-coating interaction, or how rapidly the ink tack buildup takes place when the sheet passes through the



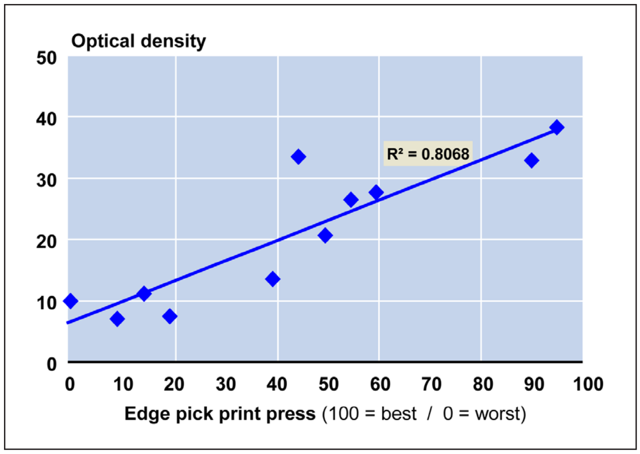
3. Optical density (IGT setoff at 60 s).



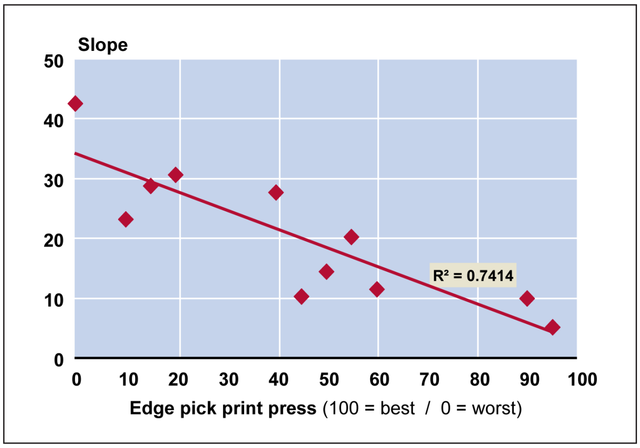
4. *Ink tack slope (P&I Test).*



5. *Ink tack of GCC 90, GCC 95, and NPSD GCC (Deltack).*



6. *IGT optical density vs. edge picking (commercial printed papers).*



7. *P&I ink tack slope vs. edge picking (commercial printed papers).*

print units. In addition to performing ink setting measurements (Fig. 3), the ink-coating interaction was determined via ink tack tests, where the ink tack buildup was recorded as a function of time. The level and rate of ink tack development are directly related to the composition of the coating formulation, with the pigments, binders, and starch constituting the most influential components [1,21,22].

Figure 4 shows the slope or rate of ink tack buildup. A steeper slope (higher number), indicating fast ink tack buildup, was obtained with finer pigments, reduced binder level, and lower solids. Similar findings were reported in several previous studies [3,5-12]. The evaluation of the number of passes to failure in the same test correlated well with the slope; a lower slope was associated with a larger number of passes to failure [23]. In other words, a low degree of interaction between the ink and the coating resulted in a high number of passes to failure and a less steep slope.

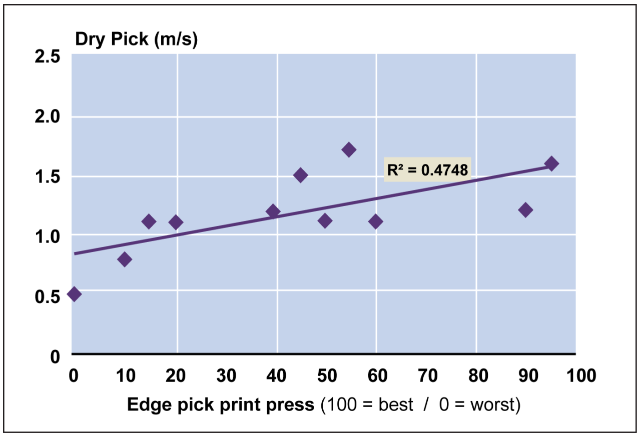
Faster ink tack buildup was observed for the NPSD GCC (TP 9) compared to GCC 95 (TP 2) at similar solids (68%) and latex level (7.5 parts), whereas ink set rates were similar. The slope difference may be attributed to the more open coating layer created with the NPSD GCC, as indicated by the mercury intrusion measurements. The ink tack test first of all measures the cohesive split within the ink, and then the surface tackiness as the ink viscosity increases. Ink setoff is more purely a surface tackiness phenomenon, as the force transmitted to the ink makes it deposit on the counter sheet.

Due to lower permeability, the ink tack on GCC 95 will reach its maximum sooner and fall off more slowly than on the NPSD GCC. This behavior is illustrated in **Fig. 5**. For comparison, the ink tack curve of GCC 90 is also included. Being more permeable, the NPSD GCC allowed the ink vehicle to drain the interior of the ink film faster, with the tack rising beyond that of GCC 95 (and GCC 90) at a higher slope. GCC 95 and GCC 90 generated similar tack curves, with GCC 90 falling off somewhat slower, reflecting the differences in pore size distribution (Fig. 2).

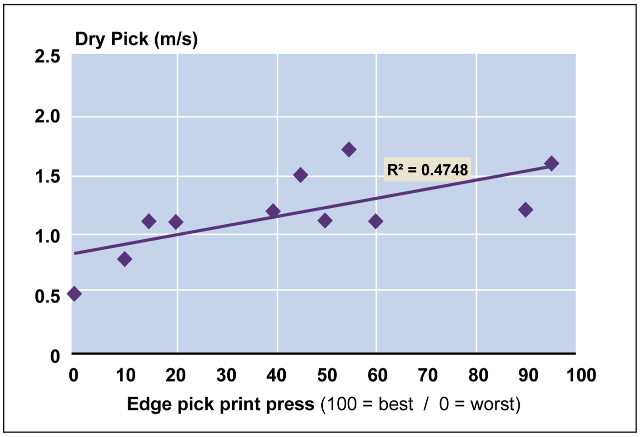
Laboratory test results vs. edge picking

As depicted in **Fig. 6**, the ink setting correlated with the degree of edge picking in the commercial printing test; only two TPs deviated from the line. Results from ink tack measurements also showed a good correlation with edge picking (**Fig. 7**) in contrast to other properties tested in the laboratory, such as dry pick (**Fig. 8**) or wet pick (**Fig. 9**).

The results indicated that quantifying the interaction between the ink and the coated surface as a function of time



8. Dry pick vs. edge picking (commercial printed papers).



9. Wet pick vs. edge picking (commercial printed papers).

was required for a sensible laboratory-scale simulation of the surface strength, as defined by the degree of tail-edge picking in multicolor SFO printing. The surface strength thus related to the rate of ink tack buildup when the ink diluent absorbed into the coating. A coating layer that created slow ink tack buildup and low tack forces showed a low degree of (edge) picking and was regarded as having a high surface strength. The rate of ink tack development was related to the rate of ink setting, which consequently made this a good indication of surface strength.

The ink setting and ink tack results showed that the developed pore structure of the coating layer, and thereby the pigment fineness, was crucial for the degree of edge picking. Fine pigments created a coating layer with a large number of very small pores (high microporosity), which generated high capillary pressure and rapid ink setting. Higher microporosity (finer pigments) also may lead to insufficient ink leveling before ink setting is completed and, thus, reduced print gloss [11,12,24]. The clay-containing formulations gave the highest degree of edge picking. This finding was most likely related to the very fast ink setting combined with the large surface area (e.g., high binder demand) and hydrophilic character of the clay.

Ink-coating interaction—pore size, solids content, and binder level

Mercury intrusion measurements provided information on the pore size distribution of the bulk coating layer. The bulk pore size related mainly to pigment fineness. Coating color solids and binder level indeed influenced ink-coating interaction; therefore, the variation of these parameters primarily affected the outermost surface of the coating, while the general structure of the coating remained unaffected by the latex binder. Scanning electron microscopy (SEM) results by Pöhler et al. [25] suggest that the latex area fraction at the surface of GCC coatings would increase from about 10% to 15% when raising the latex from 5 to 7.5 parts, while hardly being detectable in the bulk (cross-section) of the coating. Increasing the binder level above 10 parts has been shown to influence the total coating structure by sealing intrinsic pores to a greater extent, with reduced pore size and slower ink setting as a result [9].

It was also possible that the effect of the latex on ink-coating interaction at these low addition levels (5 and 7.5 parts) primarily was of chemical nature (polarity) rather than a result of introducing a significant physical barrier toward ink penetration. Several studies have reported the effect of latex modification on ink-coating interaction [1,3,5-8,22].

CONCLUSIONS

The GCC-containing coatings led to slower ink setting rates and, as a consequence, improved tail-edge picking compared to the clay-containing coatings. The pore structure of the coating was the main factor affecting the ink-setting rates for the various conditions of this study.

While calendering shifted the pore size distribution slightly toward smaller numbers, pigment particle size distribution was the major variable determining the pore structure. The smaller pores obtained with finer pigments were reflected in more rapid ink setting and faster ink tack buildup, which in turn correlated well with the degree of tail-edge pick observed in the print press. Results from dry and wet pick measurements showed poor correlation with the degree of edge picking.

Variations in binder level or coating solids content were not reflected in the pore size distribution curves. Nevertheless, both reduced binder amount and lower coating solids generated an increased ink set rate and lower edge-pick resistance. Therefore, maximizing the coating solids can to some extent compensate for the loss in pick strength when reducing the binder level, thus resulting in commercially acceptable printing performance.

The good correlation between the degree of edge picking seen on press, and ink setting as well as ink tack measurements done in the laboratory, indicated that quantifying the interaction between the ink and the coated surface as a function of time provided the most sensible laboratory-scale evaluation of the surface strength of a coated paper in multicolor sheet-fed offset printing. **TJ**

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ABOUT THE AUTHORS

Pigment particle size distribution influences ink-coating interaction and thereby the occurrence of tail-edge picking in SFO printing. We undertook this study because improved knowledge about factors influencing surface strength—evaluated as the degree of edge picking—can aid in the design of cost-effective coating colors. Another objective was to find out the most suitable laboratory test methods to simulate edge picking.

While the work in this field is extensive, about nine of the references cited confirm what we found; that is, relationships between coating pore structure and ink setting and ink tack development and their impact on print strength.

Probably the most difficult hurdle we had to overcome was developing a reliable technique for assessing picking on a sheet-fed press. Several pilot coater and print trials were conducted before a technique was developed. One main finding was that the degree of edge picking as evaluated in SFO printing showed the best correlation with laboratory test methods in which the ink-coating interaction was measured as a function of time

Individuals who are involved with the production of coated offset papers will learn more about those coating parameters that impact the surface strength of paper used for SFO printing. As a consequence, product development engineers will gain additional insights into the formulation changes necessary to avoid picking. Our paper also shows how well actual printing press results compare to data generated in a laboratory. While both are important, it is also important to understand the significance of any correlation and why the results might differ. This study points out that differences do exist between such data and also suggests how best to interpret them.

We plan to carry out further evaluations using the same experimental setup. The effect of clay type, binder type and amount, and PCC on tail-edge picking will be evaluated. We will also study factors influencing edge picking in single coating.

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