Improving the inkjet codability of folding boxboard

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ABSTRACT: Good inkjet printability requires a coating layer with good water absorption properties. A properly designed open coating structure helps to efficiently remove the water phase of the printing ink while controlling the penetration of the ink. The absorptivity of the coating is primarily dependent on the pigment type, as well as the binder type and amount. The pore volume of the coating layer can in principle be increased by introducing a structured pigment or a pigment with narrow particle size distribution. It is also important to optimize the binder type and level, with the aim to create a coating with higher void volume. The objective of this study was to achieve the best possible combination of sheet-fed offset and inkjet printability (i.e., one-color codability) by modifying the top coating formulation with respect to the calcium carbonate pigment type and the ratio of styrene-acrylate/polyvinyl alcohol.

Application: For folding boxboard coating layers, mills can focus on optimizing pigment composition rather than the binder type or amount.

Coated board products increasingly are subjected to multiple print processes. Different print methods usually require different surface properties to achieve good print quality. High-quality packages often need to function well in both sheet-fed offset and inkjet printing. Standard offset formulations are poorly compatible with the demands of the inkjet process. To ensure inkjet printability (i.e., one-color codability rather than multicolor high-speed inkjet printing), adaption of the standard offset coating formulation is necessary.

Achieving good inkjet printability requires a coating layer with good water absorption properties. The absorptivity of the coating structure can be influenced by variations in pigment type, as well as binder type and amount. Introducing a structured pigment or a pigment with narrow particle size distribution enhances the pore volume of the coating layer, thus creating a coating with higher void volume [1-3]. A structured pigment would provide suitable absorptivity for inkjet printing; however, it tends to worsen the offset print quality [2]. The ink set behavior in offset will be altered because the coating layer capillarity will change significantly. Hence, a coating pore structure that is optimized for the offset process does not provide the permeability required for obtaining high inkjet print quality [4]. Because of the differing requirements of inkjet and offset printing, it is a challenge for the coated board producer to create a coating layer that works well for both print methods.

The amount of binder needed in the coating varies depending on the type of binder applied. A binder with higher binding strength provides the possibility to reduce the total amount of binder, thus creating a more open structure. Furthermore, the binder chemistry has an influence on water absorption.

Because styrene acrylate (SA) latex binders provide excellent offset print quality and low taste and odor, they are commonly used as binders in coatings for high-end packaging board. To ensure sufficient surface strength for the converting stages (particularly gluing), the amount of binder in these grades is often relatively high. This makes it challenging to achieve a sufficiently open coating structure to promote inkjet print quality. By introducing polyvinyl alcohol (PVOH) as a co-binder, the total amount of binder can be reduced because the binding strength of PVOH is higher than that of SA latex [5].

PVOH is given a hydrophilic character by its hydroxyl groups. This enables water to readily absorb into its polymer matrix by diffusion, causing swelling of the polymer [6]. Pronounced diffusion contributes to rapid water uptake of the coating layer. Simultaneously, the swelling blocks small pores, reducing ink penetration [5,6]. Ink penetration has been shown to be more pronounced in coatings with SA latex because of a more open structure [7].

Introducing high levels of PVOH increases the high-shear viscosity of the coating color, which can have a negative impact on coater runnability because the blade or rod pressure required to reach the target coat weight will increase accordingly. Dilution of the coating color might therefore be needed, which in turn might compromise coating coverage and surface properties, such as smoothness and gloss. Increased high-shear viscosity might, however, constitute an opportunity to increase the coat weight while having a sufficiently high blade load for efficient profile control. PVOH contributes to water retention, especially at higher addition levels [8].

	TP1	TP2	TP3	TP4	TP5	TP6	TP7
Precoated base board, g/m²	245	245	245	230	230	230	230
GCC 90	80	80	80	50	50		
PCC				30			
MCC					30	15	
NPSD GCC						85	80
#1 Clay	20	20	20	20	20		20
SA latex	5	9	13	9	9	9	9
PVOH 4-98	5	3	0.5	3	3	3	3
Synthetic thickener	0.2	0.2	0.4	0.4	0.3	0.35	0.3
OBA (tetra)	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Solids content, %	64	64	64	59	59	62	64
Coat weight, g/m²	10	10	10	10	10	10	10
Brookfield viscosity, mPas	1030	980	1320	1070	1250	1000	1180
Average particle size*, D50%, mm	0.6	0.6	0.6	0.84	0.72	0.63	0.48

GCC = ground calcium carbonate; PCC= precipitated calcium carbonate; MCC = chemically modified GCC; TP = trial point;
NPSD = narrow particle size distribution GCC; PVOH = polyvinyl alchohol ; OBA = optical brightening agent.
* D50% of the total pigment system.

I. Pilot coater trial program.

The objective of this study was to achieve the best possible combination of sheet-fed offset and inkjet printability. This was accomplished by modifying the top coating formulation with respect to the calcium carbonate pigment type and the binder type.

EXPERIMENTAL

Pilot coater trials were conducted using roll application followed by a bent blade. A topcoat of 10 g/m² was applied on mill-precoated board at the machine speed of 600 m/min. The trial program is given in **Table I**. All trial points, except trial point (TP) 6, contained 20 parts No. 1 clay. Three ground calcium carbonates (GCCs) and one precipitated calcium carbonate (PCC) were evaluated. The GCCs are referred to as GCC90 (GCC having 90% of the particles below 2 µm), MCC (chemically modified GCC), and NPSD GCC (narrow particle size distribution GCC). Three different ratios of SA latex and PVOH were evaluated, and the solids content and Brookfield viscosity were kept at constant levels. A small amount of synthetic thickener was added according to the need to adjust Brookfield viscosity.

The coating colors were evaluated with respect to their viscosity at high shear rates by capillary viscometry (ACA Systems; Sotkuma, Finland), and their water holding ability by the AA-GWR method (Kaltec Scientific; Novi, MI, USA). Evaluations of ink set-off and print gloss were done using a laboratory print unit (Prüfbau; Peissenberg, Germany).

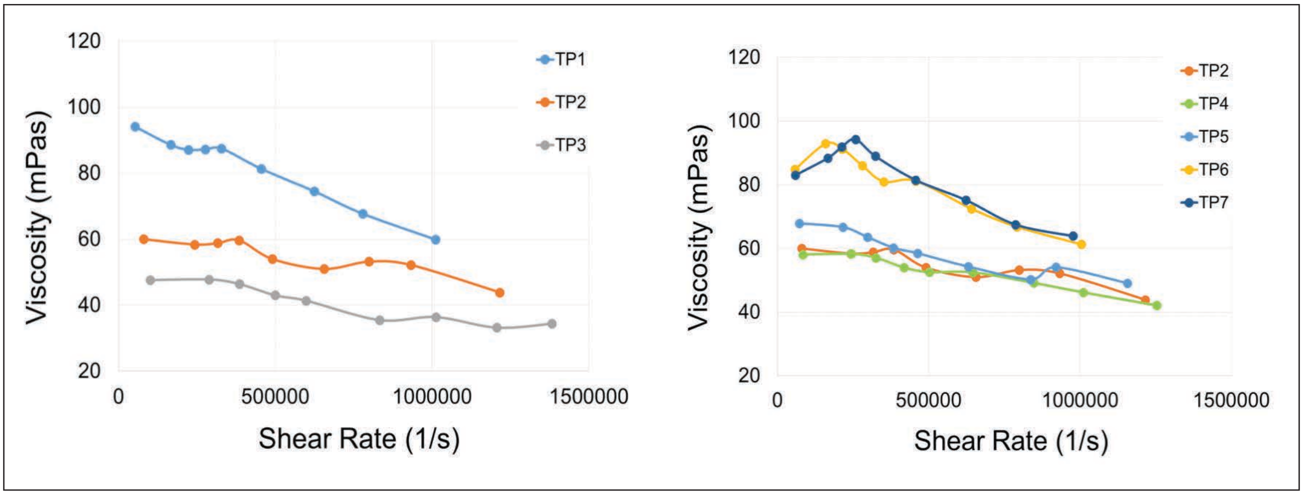
Pore size distribution data were obtained using mercury intrusion measurements (Autopore III mercury porosimeter, Micrometrics; Aachen, Germany). Pore-Comp software (University of Plymouth, Plymouth, UK) was used for correcting the mercury intrusion data. Ink tack development was tested using the ink-surface interaction test, ISIT (SeGan; St. Austell, Cornwall, UK).

Inkjet printability was evaluated using PTS-DF 103/2016 "Evaluation of the codification of folding boxboard by DOD: inkjet printers," known as the drop-on-demand method. With this method, the rub resistance of an inkjet-printed QR code can be evaluated. In the test, the sample was printed at the speed of 50 m/min and tested for rub resistance after 0.3 s by pressing an 80 g/m² copy paper against the sample surface, with a load of 1 N/cm sample width.

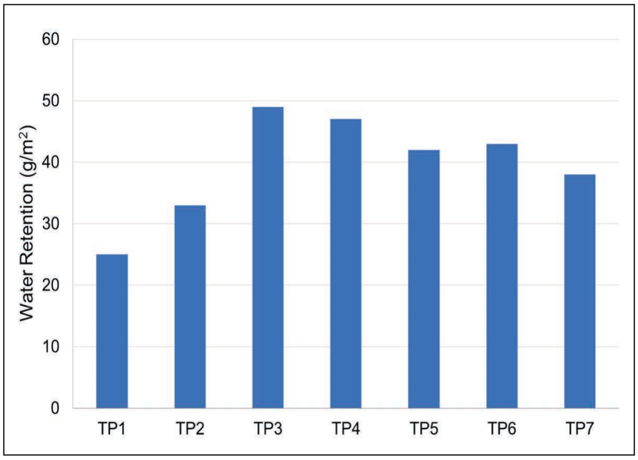
For each trial, 3000 sheets were printed on an industrial sheet-fed offset press (Stämpfli AG; Bern, Switzerland) to monitor the appearance of dust, lint, or any other deposit on the rubber blankets. Homogeneity of primary colors (mottle) was addressed by visual assessment of black and cyan full- and half-tone patterns. These were evaluated by image analysis (Verity IA; Prüfbau, Germany). Print gloss (Lehmann) was measured on 100% and 400% patterns.

RESULTS AND DISCUSSION

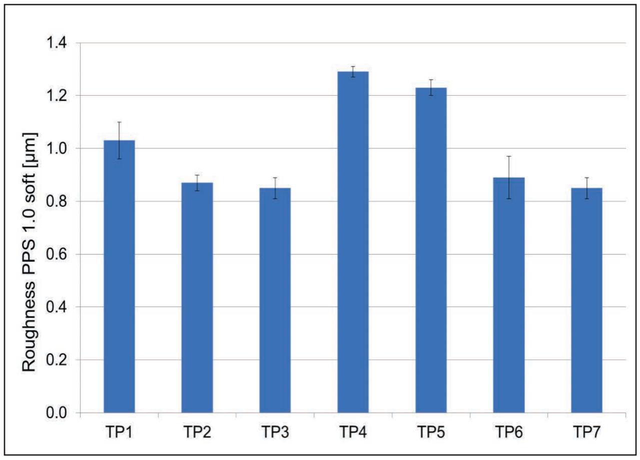
Figure 1 shows the high-shear viscosity of all coating colors, TP1–TP7. The standard offset color TP1 had the lowest viscos-



1. High shear viscosity, binders (left) and pigments (right).



2. Water retention (TP = trial point).

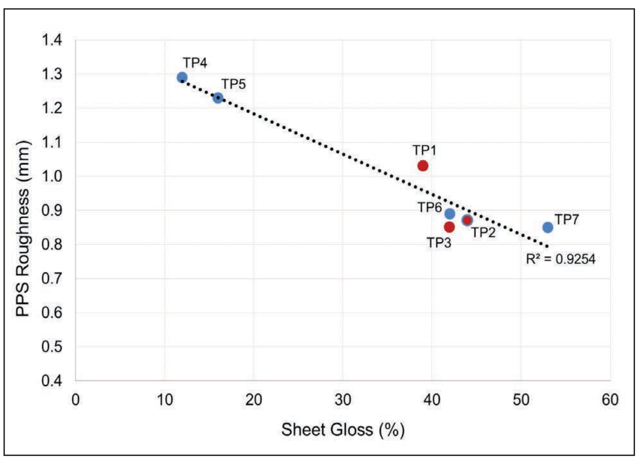


3. Parker Print Surf (PPS) roughness.

ity level. The viscosity increased with the ratio of PVOH (TP2 and TP3). When comparing the coating colors with the latex/PVOH ratio of 9/3, a significant increase in the viscosity was seen for the colors containing NPSD GCC (i.e., TP6 and TP7). Despite the strong high-shear viscosity development of some of the trial points, the coater runnability was trouble-free for all trial points.

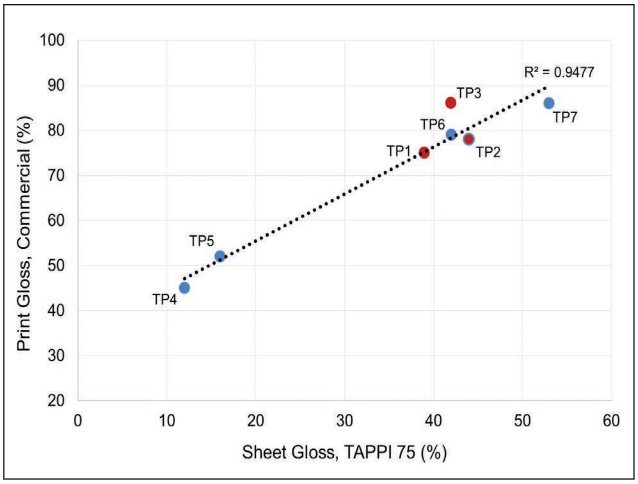
No effort was made to optimize the water retention of the coating colors. Synthetic thickener was added only to adjust Brookfield viscosity to a suitable level. As illustrated in **Fig. 2**, water retention improved as the ratio of PVOH increased (TP3–TP1). This is in line with the findings of Sandås and Salminen [8]. PVOH is a water-soluble binder and thus contributes to water retention. The special pigments used in TP4–TP7 seemed to have created a pronounced open coating structure, allowing water to drain more easily than the standard GCC pigment GCC90 (TP2).

As seen in **Fig. 3**, the Parker Print Surf (PPS) roughness decreased significantly when moving from 5 to 3 parts of PVOH binder. A further reduction from 3 to 0.5 parts had only a limited effect on the PPS roughness. The coatings based on

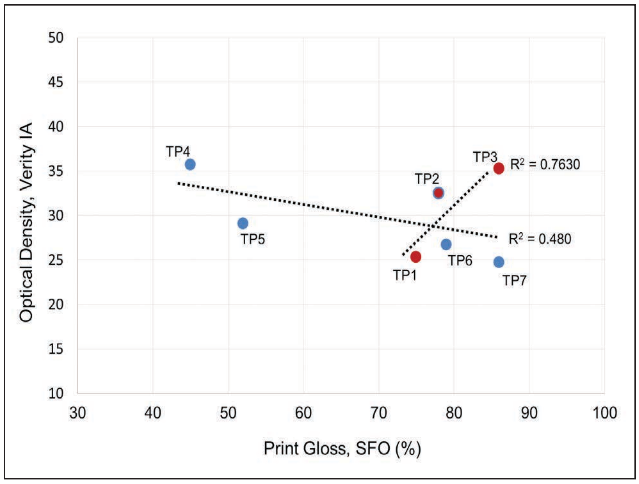


4. PPS roughness versus sheet gloss.

PCC and MCC resulted in relatively high PPS values, whereas the roughness of the NPSD GCC was on level similar to that of the GCC 90. There was a good correlation between PPS roughness and sheet gloss (**Fig. 4**). The print gloss was largely a function of the sheet gloss (**Fig. 5**).



5. Print gloss versus sheet gloss.



7. Optical density at 60 s versus print gloss (pigment and binder variation separated).

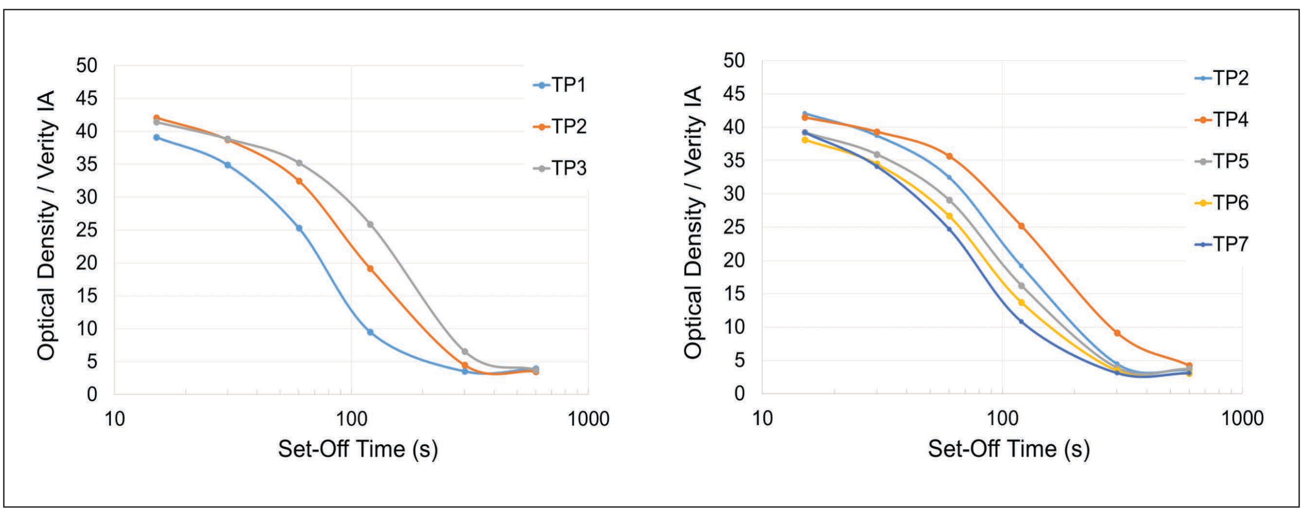
Figure 6 shows the ink-set rate in the form of the optical density measured on ink set-off samples after 60 s. A slower ink setting was observed with increased amount of PVOH, indicating the creation of a more closed surface. Compared with GCC 90, the PCC slowed the ink set rate, whereas it became faster with the MCC and NPSD GCC.

Typically, print gloss correlates well with ink set rate, in that slower ink setting relates to higher print gloss [1,2,5,9,10]. As shown in **Fig. 7**, where the optical density after 60 s of all trial points is plotted against the print gloss, such a relation was not evident in this study.

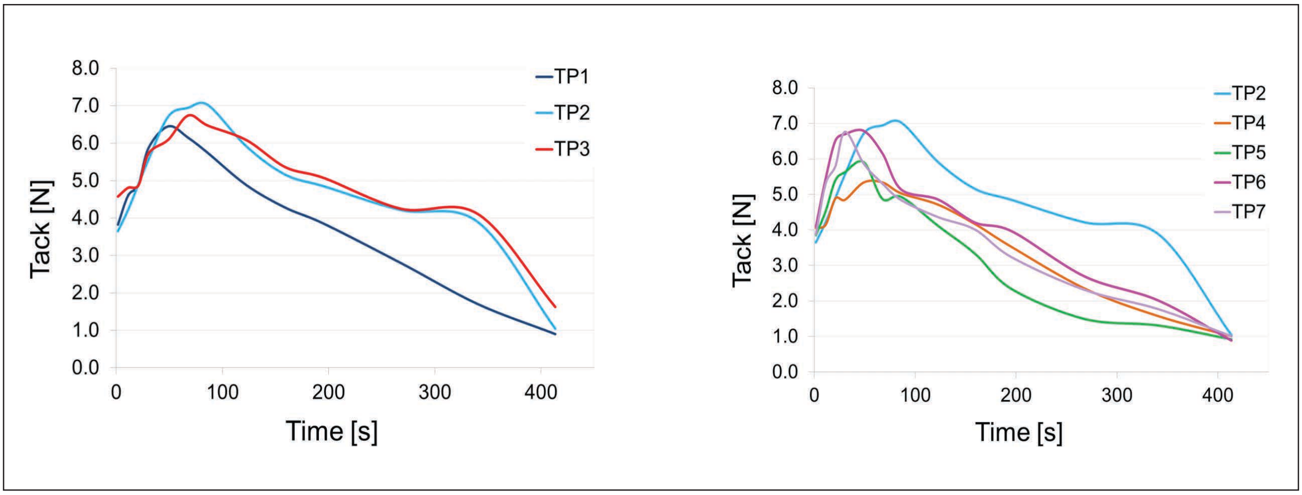
When changing the coating layer structure only by varying the binder system, while keeping the pigment system constant, the previously mentioned trend was observed. As shown in Fig. 7, TP1–TP3 all had the pigment combination 80/20 GCC/clay, and roughly the same total binding power when assuming PVOH = 1.5–2 times the binding power of SA latex. Accordingly, the total amount of binder was reduced as the ratio of PVOH was increased, leading to a less pronounced sealing of the surface and a coating with more rapid ink setting.

For TP4–TP7, the binder system was kept unchanged with respect to both type and level, whereas the pigment concept was varied. These trial points resulted in an opposite correlation between ink set rate and print gloss; more rapid ink setting was related to higher print gloss. The presence of the structured pigments in TP4 and TP5, the PCC and the MCC respectively, produced very low print gloss despite slow ink setting. Hence, the print gloss for these coatings was predominantly related to the sheet gloss, rather than to the differences in capillarity and ink set rate.

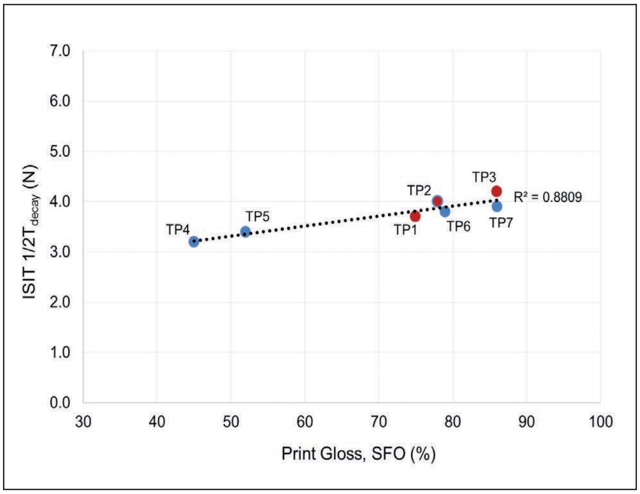
Figure 8 illustrates the ink tack curves for all trial points. TP2 and TP3 (GCC 90) clearly gave the slowest decay in the ink tack curve. TP4–TP7 all gave rapid ink tack decay, with TP5 giving the most rapid one. TP1, with the lowest total binder amount, was very similar to TP6. The low maximum tack force of TP4 and TP5 reflects the high surface roughness of these coatings.



6. Optical density of ink set-off samples; binders (left) and pigments (right).



8. Ink tack development; binders (left) and pigments (right).



9. Ink tack force at 1/2$_{decay}$ versus print gloss (sheet-fed offset).

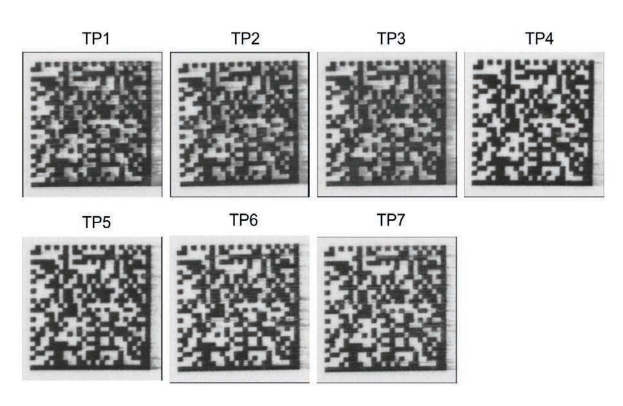
As given in **Fig. 9**, a good correlation existed between print gloss and the ink tack force measured at the half height decay (1/2$_{decay}$) away from the maximum force, which is an indication of the available pore volume in the coating [11]. In the ISIT test, considering the pigment variations at the latex/PVOH ratio of 9/3, larger pores seem to have dominated the ink set rate (D50% of the pigment system of TP4>TP5>TP6>TP7), whereas small capillaries promoted ink setting in the set-off test (Fig. 7). For TP1–TP3, higher total binder amount resulted in higher ink tack and higher print gloss.

Results from sheet-fed offset printing are given in **Table II** in the form of visual assessment of the print quality, print mottling as evaluated by image analysis, and print gloss. On the basis of the results, a ranking of 1–7 (1 = best, 7 = worst) was obtained for each evaluation. The individual rankings were then summarized, which again was used to get a total ranking. Not surprisingly, TP3, which represents a typical offset formulation for folding boxboard, was graded to have the best offset print quality, followed by TP2 and TP1, the two other GCC 90/clay trial points.

Inkjet printability was evaluated using a coding test developed by PTS in Munich, Germany. Test results are shown in **Fig. 10** and **Table III**. Without rub, TP1–TP4 provided very good print quality. However, with rub TP3, which was ranked best in terms of sheet-fed offset printability, gave the worst inkjet print results. The other two trial points with GCC 90, TP1 and TP2, also failed to provide sufficient rub resistance, despite modifications in the binder system. This indicates insufficient penetration of the water phase into the pore structure of the coating layer, leaving the ink poorly bound to the surface. Furthermore, it is important to consider the fact that only one color was applied in the coding test. In multicolor

	TP1	TP2	TP3	TP4	TP5	TP6	TP7
Visual assessment	1	1	1	5	4	7	6
Mottling	3	2	1	6	4	5	7
Gloss	5	4	1	7	6	3	2
Sum	9	7	3	18	14	15	15
Ranking	**3**	**2**	**1**	**7**	**4**	**5**	**5**

II. Sheet-fed offset print results, ranking (1 = best, 7 = worst).

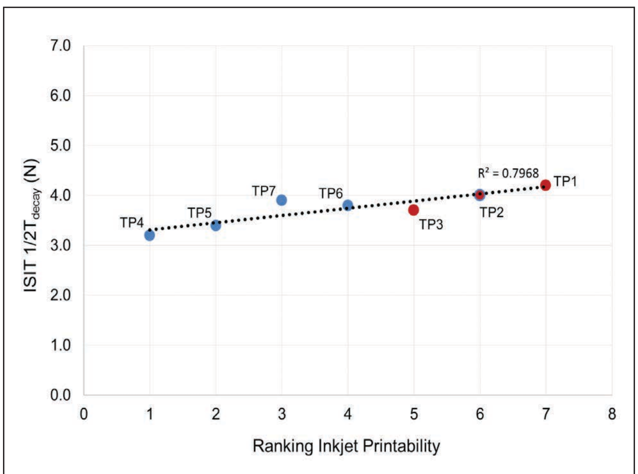


10. Inkjet coding results; rub resistance after 0.3 s.

Inkjet Print Quality				
	Without Rub	Rub After 0.3 s	Rub After 0.5 s	Rub After 1.0 s
TP1	4	0	0	1
TP2	4	0	0	1
TP3	4	0	0	2
TP4	4	2	3	4
TP5	3	1	3	4
TP6	3	1	2	2
TP7	3	1	3	3

Very good		Average		Bad
4	3	2	1	0

III. Ranking of inkjet coding quality (0–4, worst to best).



11. Ink-tack decay versus inkjet print quality ranking.

printing, this lack of ink-coating adhesion would most likely cause severe intercolor bleeding. TP3 had the highest total amount of binder of the trial points. The best rub resistance of the inkjet-printed QR code was obtained with TP4 and TP5, the PCC and the MCC, respectively.

The measured ink tack force at the half height away from the maximum tack ($1/2_{decay}$), which is considered to indicate the degree of total pore volume available, correlated well with print gloss (Fig. 9). As shown in **Fig. 11**, this indirect measure of available pore volume provided a means of estimating inkjet print quality. A lower force at $1/2_{decay}$ correlated with improved rub resistance.

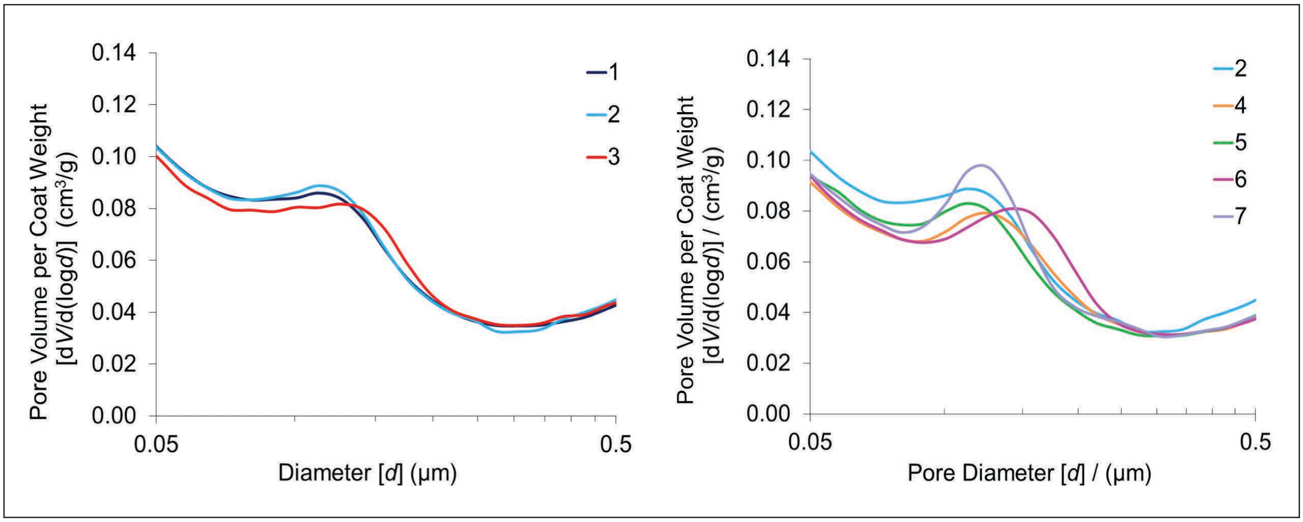
Mercury porosimetry was performed on the coated samples to visualize the effect of the pigment and binder variations on pore structure. **Figure 12** shows the pore volume for the pore diameters between 0.05 and 0.5 µm. The effect of binder variation is illustrated in the figure to the left. When moving from the ratio of 5/5 latex/PVOH (TP1) to 9/3, the peak remains at the pore diameter of approximately 1.5 µm, and there is only a marginal reduction of the peak. When minimizing the PVOH content to 0.5 parts (TP3), the peak decreases and shifts toward a larger pore size.

The pigment variations at constant binder system, nine parts latex and three parts PVOH, are shown to the right in Fig. 12. The effect of the narrow particle size distribution TP7 was seen in the form of a distinct and narrow peak at 0.1 µm. TP6, with no clay, resulted in a similar but slightly wider peak at a larger pore diameter, reflecting the lack of the very fine clay particles.

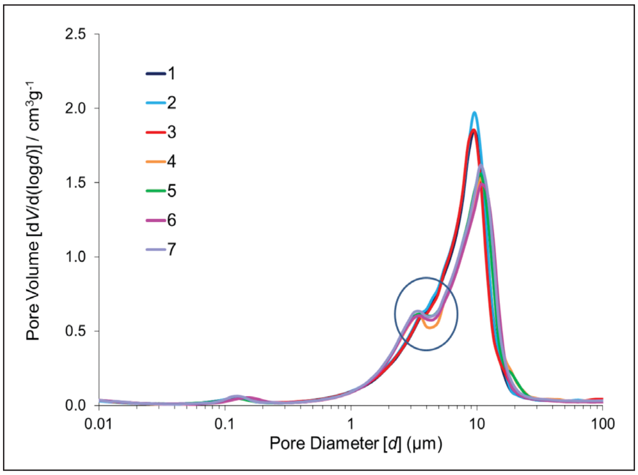
The relatively small variations in the pore distribution curves shown in Fig. 12 cannot explain the differences in inkjet print quality. When also considering larger pore diameters, which include the influence from both the base board and the coating (**Fig. 13**), it is obvious that the special pigments used in TP4–TP7 result in a bimodal pore distribution with a second peak at the pore size of approximately 3 µm. This additional pore volume significantly contributes to the absorption ability of the coating. The difference between TP1–TP3 and TP4–TP7 at the pore size range 4–10 µm comes from the difference in base board grammage, 245 g/m² and 230 g/m², respectively.

The results from the mercury porosimetry measurements also suggest that rub resistance is a function of the available pore volume of the coating. TP4–TP7 all exhibited a bimodal pore size distribution. The existence of the larger pores at the pore diameter of 3–4 µm is believed to contribute significantly to the absorption ability of the coating. This confirms that large pore volume is of utmost importance to achieve sufficient absorptivity and thus good inkjet print quality.

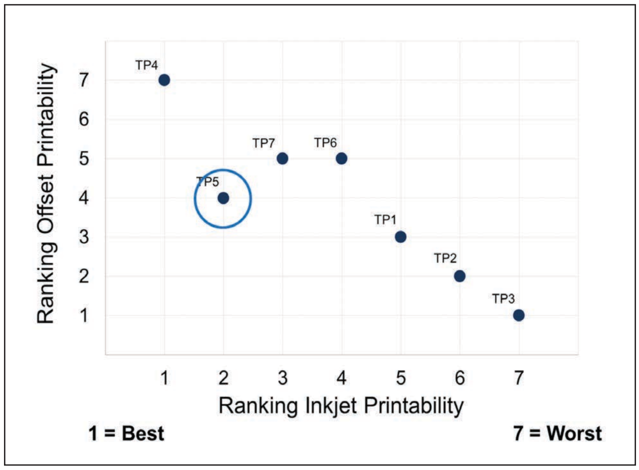
This study confirmed the difficulty of combining offset and inkjet printability without carefully modifying the standard offset formulation. As depicted in **Fig. 14**, there was an overall negative correlation between sheet offset and inkjet print quality. The best compromise was obtained with TP5 (MCC).



12. Pore size distribution as measured by mercury porosimetry; binders (left) and pigments (right.)



13. Pore size distribution as measured by mercury porosimetry.



14. Offset print quality ranking versus inkjet print quality ranking.

CONCLUSIONS

Two approaches were followed in the attempt to increase the coating layer absorptivity of folding boxboard and thus obtain improved inkjet printability (i.e., inkjet codability). The first was to replace part of the SA latex with PVOH, while simultaneously reducing the total binder amount. The second was to introduce special calcium carbonate pigments into the coating formulation.

Overall, a negative correlation existed between sheet-fed offset and inkjet printability. Whereas the standard offset formulation of 80/20 GCC 90/clay and 13/0.5 SA latex/PVOH as expected, provided the best sheet-fed offset print quality, the same formulation was the least suitable one for inkjet printing because it showed the poorest ink rub resistance. By changing the binder system to higher levels of PVOH, inkjet print quality only improved to a very limited extent. However, by mixing morphologically different pigments, the coating structure was disrupted enough to obtain efficient absorption with a subsequent improvement in rub resistance.

The effect of the special pigments on the pore structure was also demonstrated by ink tack measurements. The ink tack force at the half height decay from the maximum of the tack curve was shown to correlate with inkjet print quality (the lower the force, the better the print quality). Further evidence of the importance of the pore characteristics for inkjet printability was obtained from mercury porosimetry. These measurements showed that the coatings containing the special pigments resulted in a bimodal pore size distribution with the presence of additional coating pore volume at larger pore diameters.

On the basis of our findings, additional trials are planned to further optimize the coating pore structure with respect to inkjet coding while securing a high-quality sheet-fed offset print result. **TJ**

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About this journal

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We chose this subject because inkjet codability has become an increasingly important feature in packaging. The work differs from previous research in that special calcium carbonate pigments have been evaluated at the pilot scale to obtain inkjet codability and good offset print quality. Furthermore, the effect of binder type and level has been investigated.

The most challenging aspect was putting a number on the inkjet codability, which we achieved by using a PTS test method. An interesting finding was that inkjet codability can be improved by introducing 20–30 parts of a specialty pigment. However, maintaining good offset print quality is challenging. We were surprised by the finding that the inkjet codability is much more influenced by variations in the coating structure caused by pigments than by changes in the binder type or amount.

This work indicates that mills can primarily work on optimizing the pigment composition rather than the binder type or amount. We plan to conduct additional studies by applying specialty GCCs to further improve inkjet codability, without compromising offset print quality.

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