CAN STARCH BE USED IN TOPCOATING?

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GCC

KAOLIN

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Pigments for Paper

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ABSTRACT

Three pigment systems (two GCC/ultrafine kaolin blends and 100% ultrafine GCC) have been applied to a commercial precoated woodfree base using a range of starch and latex combinations. This has allowed the determination of the combinations that produce the same offset printing strength, as measured by dry pick. All of the coating paper and print properties measured can then be assessed at these constant strength combinations. This means that it is possible to determine if the quality is acceptable when trying to reduced costs by utilising higher levels of starch in topcoating. There is also evidence that the presence of kaolin and the use of GCC with different particle sizes can have a significant affect on the starch to latex levels required to achieve the target dry pick values. Although there is a different balance of properties, the use of 100% ultrafine GCC is a viable alternative to the traditional fine GCC/ultrafine glossing kaolin.

BACKGROUND

As papermakers look for ways to reduce costs, the potential for using a lower cost binder should be explored. Although starch is used widely in precoating, it is rarely used in topcoating, usually due to fears about printability. This study compares a wide range of starch and latex levels with three pigment systems that can be found in commercial use. In particular, it compares traditional fine GCC/ultrafine glossing kaolin blends with a relatively new approach of using 100% ultrafine GCC. Depending on the geographical location of the papermaker (away from North America or Brazil), it may be possible to lower pigment costs by reducing or removing the level of the relatively expensive glossing kaolin in the topcoat.

All of the measurements are designed to answer the questions: what is the lowest cost binder combinations that can be used to obtain good paper performance and what effects does pigment selection have on these binder combinations?

EXPERIMENTAL DETAILS

An 83 g/m^2 precoated commercial European woodfree base paper was used as the coating substrate (see Table I).

Table I. Base paper properties

Substance	83.1	g/m^2
Ash	17.7	%
Cobb (60 s)	58	g/m^2
Brightness (D65/10)	100.3	
L*	95.9	
a*	1.9	
b*	-7.5	
Whiteness	123	
Opacity	87.8	
PPS (1000 kPa)	4.3	µm

Four pigments were used in three topcoat formulations: 100% GCC-99, 85%/15% GCC-90/Kaolin, 85%/15% GCC-95/Kaolin. The pigment properties are given in Table II. Typically, a combination of fine GCC and glossing kaolin is used to achieve an acceptable balance of gloss, optics and printability. As an alternative, 100% of an ultrafine GCC may be used.

Table II. Pigment properties

	Kaolin	GCC-90	GCC-95	GCC-99	85% GCC-90 15% Kaolin	85% GCC-95 15% Kaolin
Dry pigment brightness (ISO R457)	88.8	94.9	94.7	95.2	-	-
Sedigraph < 2 µm content (%)	98	90	96	99	-	-
Sedigraph < 1 µm content (%)	96	64	76	84	-	-
Sedigraph < 0.5 µm content (%)	86	37	45	52	-	-
Sedigraph < 0.25 µm content (%)	57	20	25	28	-	-
Mean particle size (µm)	0.22	0.71	0.56	0.48	0.60	0.48
Surface area (m^2/g)	21.3	11.0	16.1	16.7	12.5	16.9

A range of formulations based on different starch and latex levels were used with each pigment system (see Table III). A styrene-butadiene latex (Dow 920) and a modified starch (Cargill C*Film7312) were the binders used. When no starch was present, a low molecular weight CMC was used (FinnFix 5). An AZC cross-linker (Bacote 20) was used in association with the starch. A constant level of optical brightening agent (OBA Blankophor P) was also used. The pH was adjusted to ~9 using NaOH.

Table III. Formulations (based on 100% pigment)

	a	b	c	d	e	f	g	h
SBR latex (pph)	6	10	6	2	6	2	6	8
Starch (pph)			2	4	4	8	8	4
AZC cross-linker (pph)			0.2	0.4	0.4	0.8	0.8	0.4
OBA (pph)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
CMC (pph)	0.5	0.5						

The coatings were applied using a Helicoater at 600 m/min using a short dwell head with blade metering. The target coat weight range was 9.5 to 10.5 g/m^2. Between 2 and 4 coatings were prepared for each pigment/formulation combination. The coatings were applied at the highest possible solids (between 65.2% and 71.2%) that could be used without any runnability or paper quality issues (data in Table IV).

Table IV. Coating Properties

		Formulation							
		a	b	c	d	e	f	g	h
100% GCC-99	Solids (%)	68.8	68.7	70.1	69.8	68.2	66.0	65.2	67.9
	Brookfield 100rpm (mPa.s)	2220	2340	376	676	630	1070	1042	688
	Paar Physica 12000s^{-1} (mPa.s)	76	70	81	144	92	157	119	95
	AA-GWR (g/m^2)	159	184	106	68	80	12	11	71
85% GCC-90 15% Kaolin	Solids (%)	70.8	70.1	71.2	69.6	69.9	67.4	66.7	69.4
	Brookfield 100rpm (mPa.s)	2340	2320	500	750	1180	1840	1660	930
	Paar Physica 12000s^{-1} (mPa.s)	130	109	138	158	171	259	212	143
	AA-GWR (g/m^2)	113	109	88	65	57	38	39	56
85% GCC-95 15% Kaolin	Solids (%)	69.3	68.8	70.2	68.8	69.6	67.3	66.1	69.4
	Brookfield 100rpm (mPa.s)	2320	2340	540	670	1180	1980	1920	1140
	Paar Physica 12000s^{-1} (mPa.s)	101	87	104	165	177	265	219	155
	AA-GWR (g/m^2)	106	103	86	68	59	38	39	60

The coated papers were conditioned at 50% relative humidity and 23°C for 24 hours before calendering. The coated papers were passed through a Perkins laboratory calender for 10 nips at 36 m/min, with a nip load of 89 kg/cm and a steel roll temperature of 65°C. The coated calendered papers were conditioned again at 50% relative humidity and 23°C for 24 hours before testing.

A DataColor Elrepho 3300 was used to measure the optical characteristics of the papers using D65/10 illumination (CIE L*a*b*, opacity, whiteness and brightness). The optics were measured both with a calibrated level of UV present and with the -420nm UV cut-off filter. Kubelka-Munk theory was used to calculate the light scattering (S) and absorption (K) of the coated papers at the same wavelength as brightness and opacity (457 and 560 nm respectively) using the -420nm UV data. In addition, a wavelength exponent can be calculated from the gradient of a plot of log(S) against log (wavelength), where a higher gradient indicates a smaller scattering size [1]. A Parker Print Surf was used to measure surface roughness at a pressure of 1000 kPa with a hard backing. A Hunterlab gloss meter was used to measure 75° TAPPI gloss.

Offset print gloss (TAPPI 75°) and density (using SpectroEye densitometer) was investigated using an IGT laboratory printing unit at 0.5 m/s and 500N pressure. 0.3 cm^3 of a commercial magenta quickset ink was applied to the distribution rollers. This results in an ink film thickness of ~1µm on the paper. No significant picking or sever mottle was seen during this printing. 512x512 pixel 256 greyscale images were collected of the printed areas using an HP5400c scanner at 300 dpi. The FFT band-pass filter in ImageJ was used to remove any small features (<1 mm) from the images. The standard deviation of these filtered images was used as an estimation of print mottle.

Dry pick was measured using the IGT as the speed at which picking occurs in accelerated mode up to 6 m/s using an oil with a viscosity of 17.5 Pa.s. Wet pick was estimated as the speed at which picking occurs when using a Prufbau laboratory printing unit with a pre-damped paper and a specific tack graded ink in accelerated mode up to 3 m/s. This wet pick test is more severe than the conditions that are normally seen in offset printing.

The IGT was also used to provide an estimate of relative coating permeability by measuring a stain area created by applying a fixed volume droplet of a dyed liquid.

Each measured coating and paper property was analysed at the same printing strength (as measured by dry pick). A 3D surface was fitted using a root mean squares (RMS) approach to each of the measured parameters with respect to starch and latex content.

Two equations were used during the fitting process:
$z = \mathrm{a}x + \mathrm{b}y + \mathrm{c}$ (Equation 1)
$z = \mathrm{a}x + \mathrm{b}xy + \mathrm{c}y + \mathrm{d}$ (Equation 2)
where z is the dry pick value, x is the latex level, y is the starch level and a, b, c, d are fitted constants.

Equation 2 was only used when the data varied significantly from a planar fit, as seen in a significantly smaller RMS value. Figure 1 shows an example of some typical dry pick data and the 3D fit using Equation 2 (e.g. RMS using Equation 1 is 29.5, RMS using Equation 2 is 23.0).

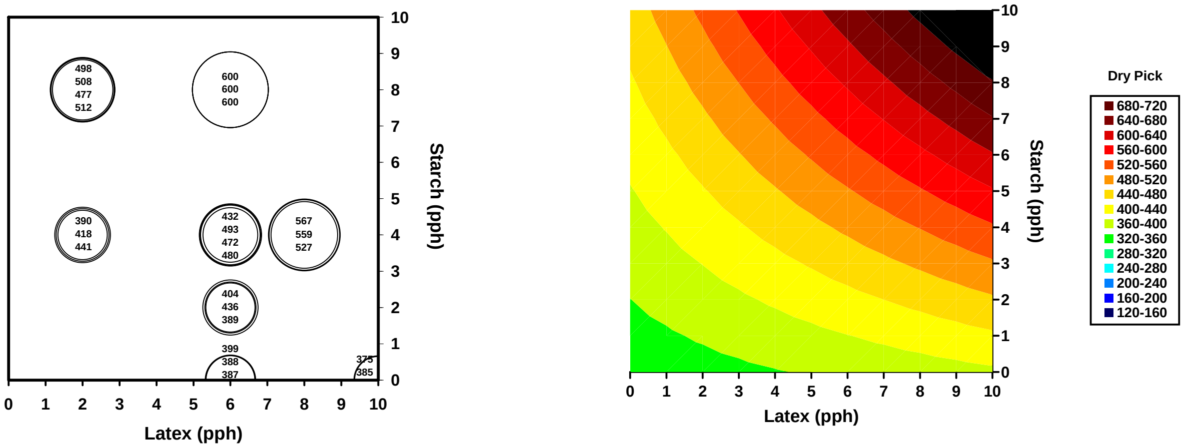

Figure 1: Typical 3D fit to dry pick data

The resulting 3D surface fit can be used to produce simplified bar charts that relate how much starch and latex is required to achieve a given dry pick strength, as shown in Figure 2.

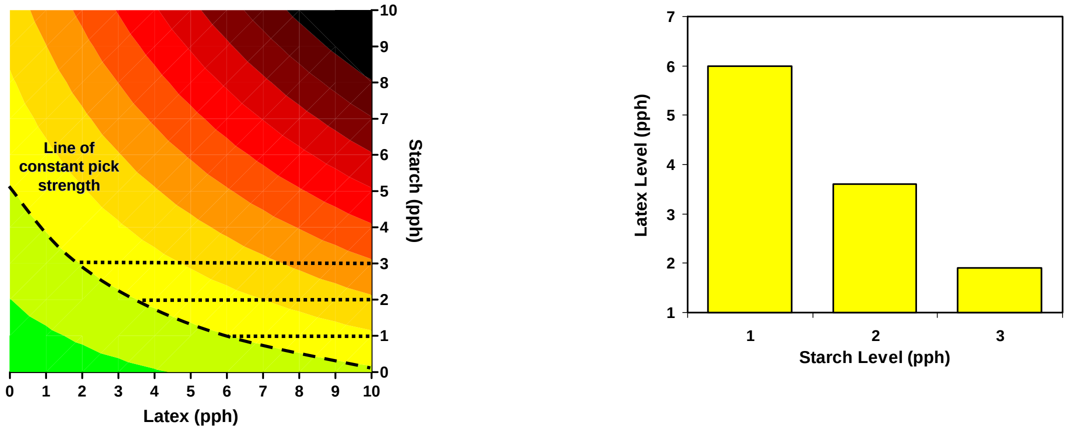

Figure 2: Extracting data from a 3D fit at constant dry pick strength

This line of constant pick strength can then be used to calculate the other coating and paper properties at constant dry pick strength. Figure 3 shows an example for sheet gloss (RMS using Equation 1 is 1.7, RMS using Equation 2 is 1.7).

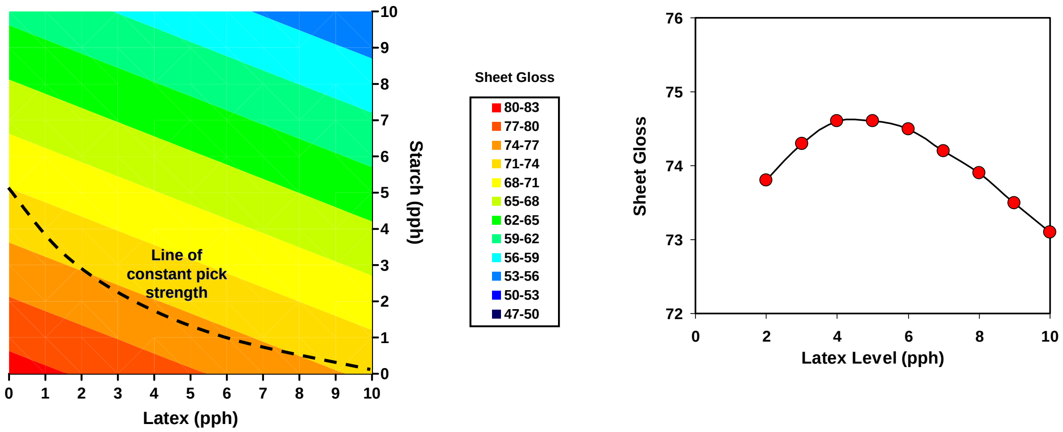

Figure 3: Calculating sheet gloss at constant dry pick

A dry pick level of 500 cm/s was selected to represent a value for coating strength that would be able to survive any typical offset printing processes.

In addition to calculating the level of latex and starch required to achieve the target dry pick strength, it is also possible to estimate the relative cost of the different starch/latex combinations. The relative cost of latex was taken to be 1.83 times that of starch, typical of commercial values for a European mill in mid 2009 [2].

RESULTS

The 3D surface fits to dry pick for the three pigment systems are shown in Figure 4. The 3D plot for the GCC-95/Kaolin uses Equation 1 (RMS using Equation 1 is 42.0, RMS using Equation 2 is 41.9), whereas the 3D plots for GCC-90/Kaolin (RMS using Equation 1 is 32.8, RMS using Equation 2 is 32.4) and GCC-99 use Equation 2 (RMS using Equation 1 is 29.5, RMS using Equation 2 is 32.0). The 3D surface for GCC-99 deviates most from a planar fit.

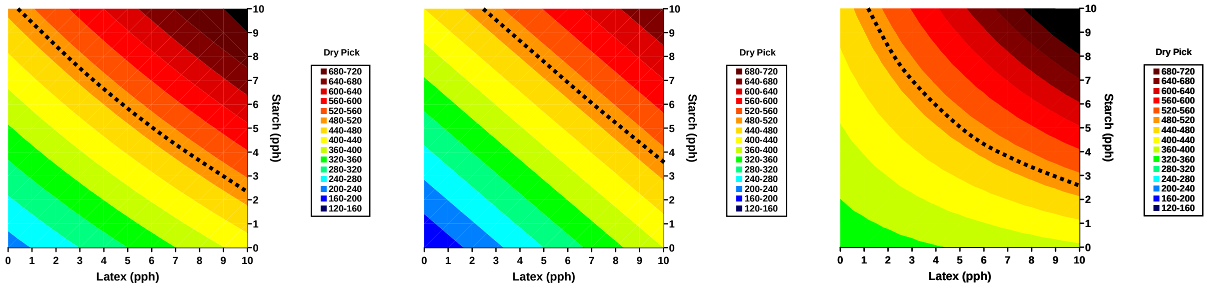

Figure 4: 3D surface fits of dry pick for GCC-90/Kaolin (left), GCC-95/Kaolin (middle), GCC-99 (right). The dotted line shows a contour indicating a dry pick value of 500 cm/s.

The level of starch and latex to achieve the target dry pick level for the three pigment systems is shown in Figure 5. The GCC-95/Kaolin blend required significantly more starch at a given latex level or more latex for a given starch level compared to the other two pigment systems. The GCC-99 required only slightly less starch or latex relative to the GCC-90/Kaolin blend. Traditionally, this might have been explained by the relative surface areas of the three pigment systems, with the GCC-95/Kaolin (16.9 m^2/g) having the highest and hence maybe having the greatest "binder demand". However, this does not account for the differences, as the pigment system with the lowest surface area is GCC-90/Kaolin (12.5 m^2/g) and this has a similar binder requirement compared to GCC-99 (16.7 m^2/g). The particle shape, GCC is blocky and kaolin is platy, and surface chemistry is likely to cause a different strength of interaction with the starch and latex.

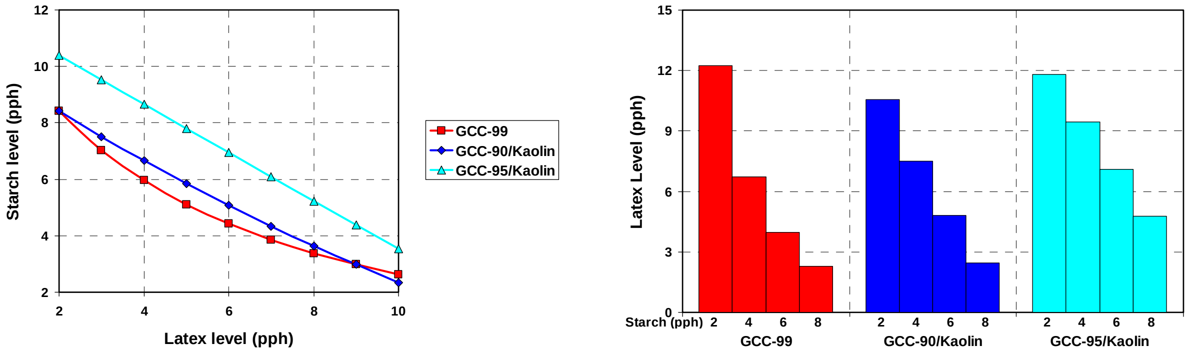

Figure 5: The starch and latex levels required to achieve the target dry pick value.

The relative cost of the topcoat binder system can also be seen in Figure 6. The lowest cost occurs when there is less latex and hence more starch present. The GCC-95/Kaolin system is the most expensive, as it requires more binder to reach the target dry pick level.

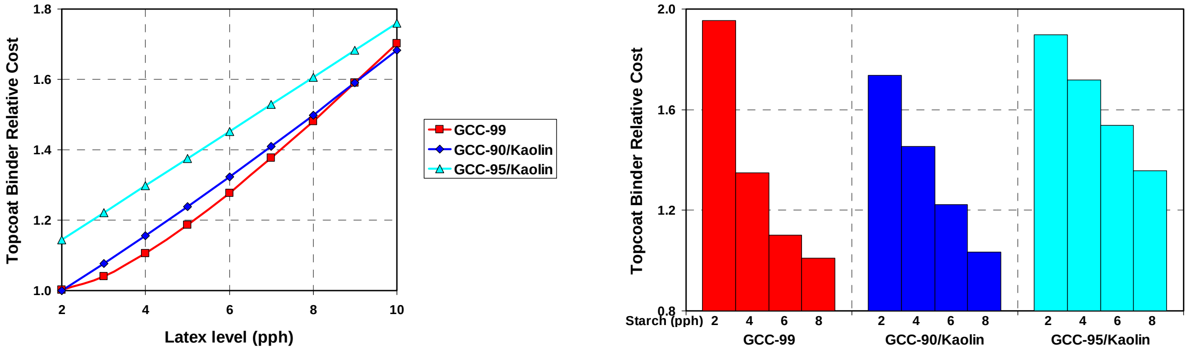

Figure 6: The relative cost of the topcoat binders to achieve the target dry pick value.

The coating properties are shown in Figure 7. As the amount of latex increases, and hence the binder cost increases, the coating solids also increases when kaolin is used. However, when the GCC-99 is used, there is less benefit in using higher latex levels. The coarser pigment blend, GCC-90/Kaolin, has the highest coating solids at a given binder cost. The water loss is less when there is less latex and more starch present. At higher levels of latex, the use of kaolin and a finer GCC tends to help control the amount of water lost. The low shear viscosity (Brookfield) tends to increase with higher levels of latex, which is probably due to the higher solids level. However, the medium shear viscosity (Paar Physica) tends to decrease with higher levels of latex/lower levels of starch. Reducing the level of starch is likely to lower both the fluid phase viscosity and particle-particle interactions.

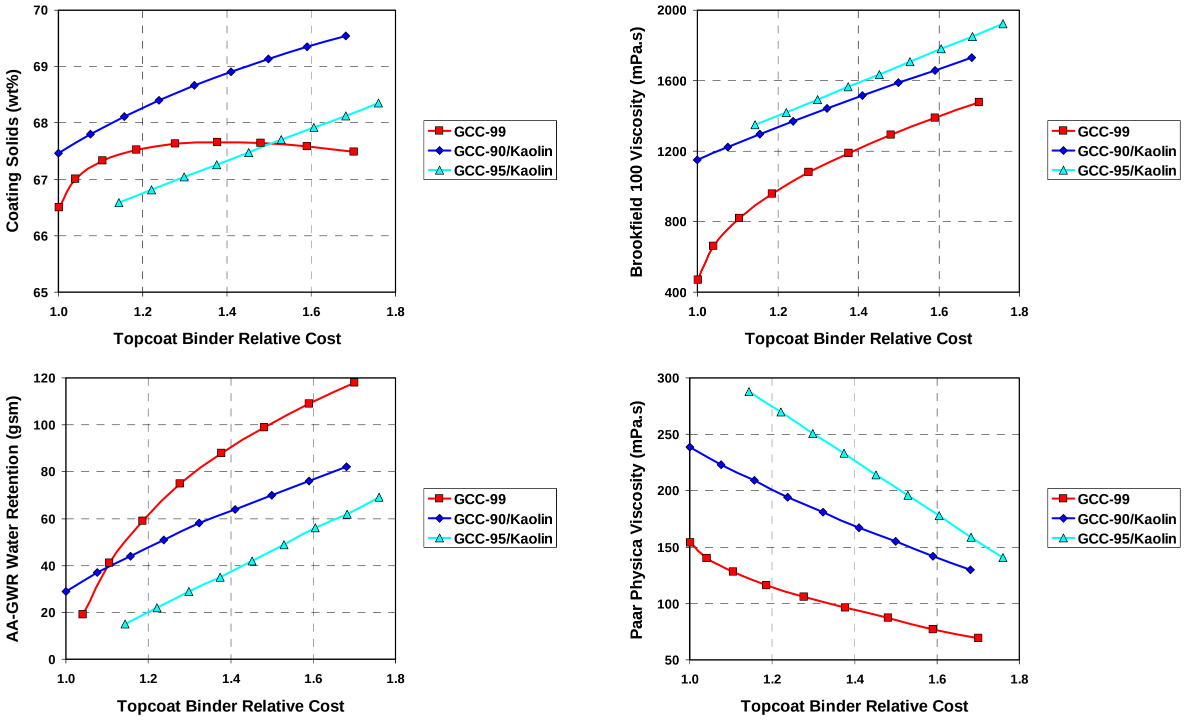

Figure 7: Coating formulation properties – Coating solids (top left), water retention (bottom left), low shear viscosity (top right), medium shear viscosity (bottom right) at the target dry pick value.

The standard paper properties are shown in Figure 8. For the two pigment systems using kaolin, higher levels of starch (lower cost option) result in a significant reduction in sheet gloss. However, there is less of an effect on the GCC-99, with only a small drop in gloss with the highest starch levels. The smoothness of the paper improves as the level of latex increases, but the smoothness of the GCC-99 appears to be slightly more sensitive to binder composition.

There is little difference in smoothness between the two kaolin containing blends and the GCC-99 pigment system gives slightly smoother paper. The use of kaolin reduces the brightness and whiteness slightly and has only a very small beneficial effect on opacity.

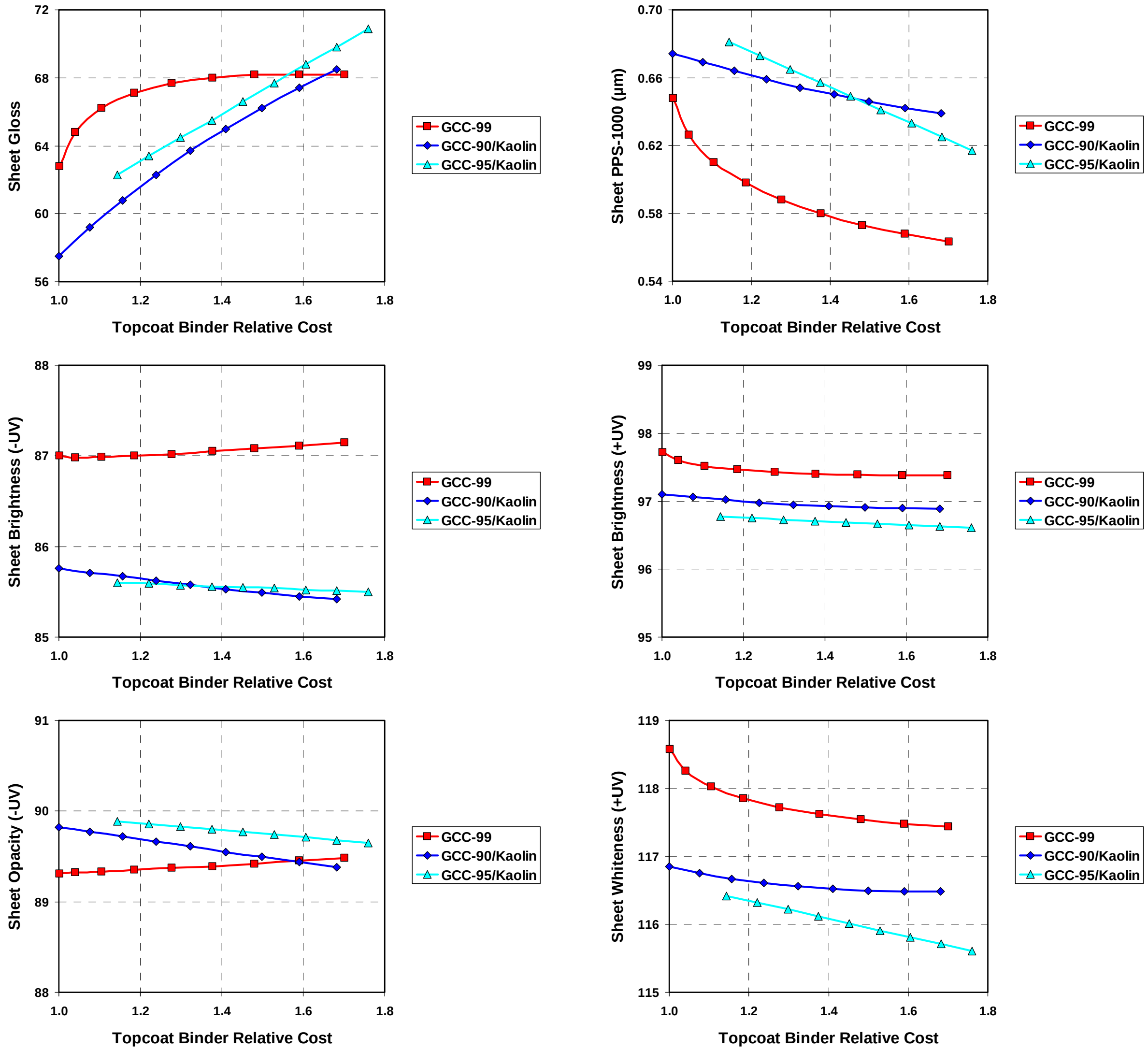

Figure 8: Paper properties – sheet gloss (top left), smoothness (top right), brightness –UV (middle left), brightness +UV (middle right), opacity (bottom left) and whiteness (bottom right) at the target dry pick value.

The light scatter and absorption properties of the coated papers are given in Figure 9. These show a subtle difference between the GCC-99 and the two blends using kaolin. When kaolin was used, the sheet scatter decreased slightly with increasing latex level, whereas when no kaolin was used the sheet scatter increased slightly. It is well known that SBR latex has a tendency to interact with GCC and thicken the coating and this effect may have caused some minor flocculation and structuring in the GCC-99 coatings. It is also possible that the starch may be interacting more with the kaolin, so reducing the starch allows a better, more closer packed coating layer. The light absorption of the coated sheets was not affected by the change in latex and starch levels. Kaolin tends to have coloured impurities that absorb in the blue region, so the blends produce coatings with higher sheet absorption at 457 nm.

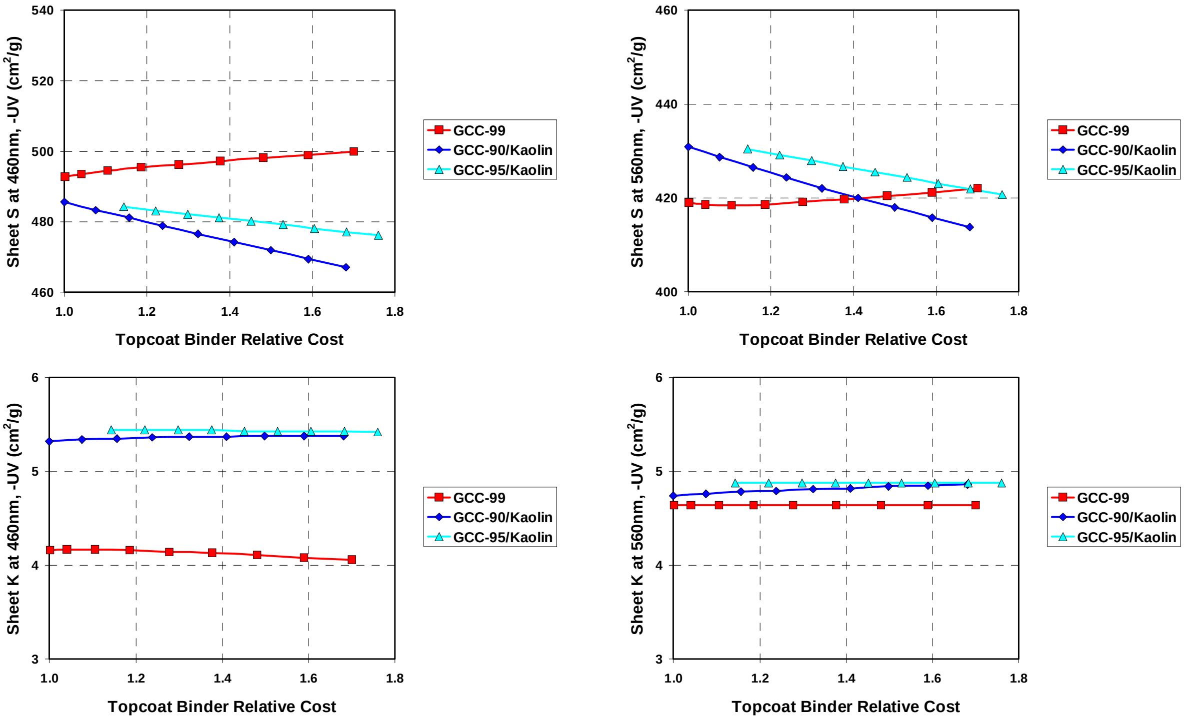

Figure 9: The light scatter and light absorption of the coated sheets at 457 nm and 560 nm at the target dry pick value.

The wavelength exponent of the sheets can be used to explain the difference in light scattering at the two wavelengths. The data in Figure 10 shows that the GCC-99 coated papers had a higher wavelength exponent compared to the blends containing kaolin. This indicates that the GCC-99 coatings had a smaller scattering size, even though the particle size distributions of the GCC-95/Kaolin blend and GCC-99 are almost the same. The platy shape of the kaolin particles has tended to disrupt the packing of the blocky GCC particles, thus increasing the size of the pores in the coating layer. The smaller pores in the GCC-99 coatings are better at light scattering at shorter wavelengths, but less so as the wavelength increases, i.e. the gradient of a plot of scatter against wavelength is higher for the smaller pores in the GGC-99 coatings. The wavelength exponents for the two GCC/Kaolin blends are similar because the kaolin is more likely to disrupt the packing of the smaller particles in the finer GCC-95, whereas when the GCC-90 is used, the ultrafine kaolin may simply occupy the pores between the larger GCC particles.

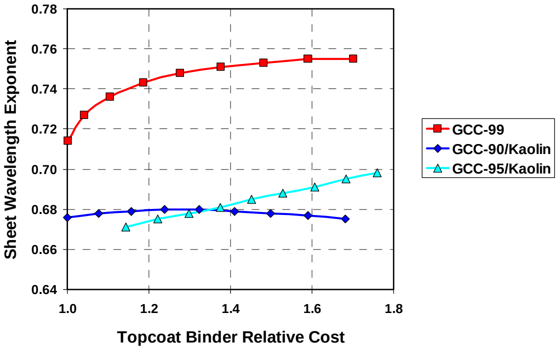

Figure 10: The wavelength exponent of the three pigment systems at the target dry pick value.

The print quality was assessed using an IGT and the values are displayed in Figure 11. As the cost (and hence latex level) increases, so does the print gloss. There are only small differences in print gloss between the three pigment systems, with the GCC-95/Kaolin blend being marginally higher than the other two pigment systems. Print density follows a similar trend.

Print snap (print gloss – sheet gloss) does not follow such a simple trend. When kaolin is used, the print snap decreases with increasing cost and latex level. However, when the GCC-99 was used, there was a more complex relationship, with higher print snap values at both very high and low latex levels.

The degree of print mottle was significantly worse for the GCC-95/Kaolin blend compared to the other two systems. The use of kaolin also tended to reduce print mottle as the relative cost and latex level increased, but the opposite occurred for GCC-99.

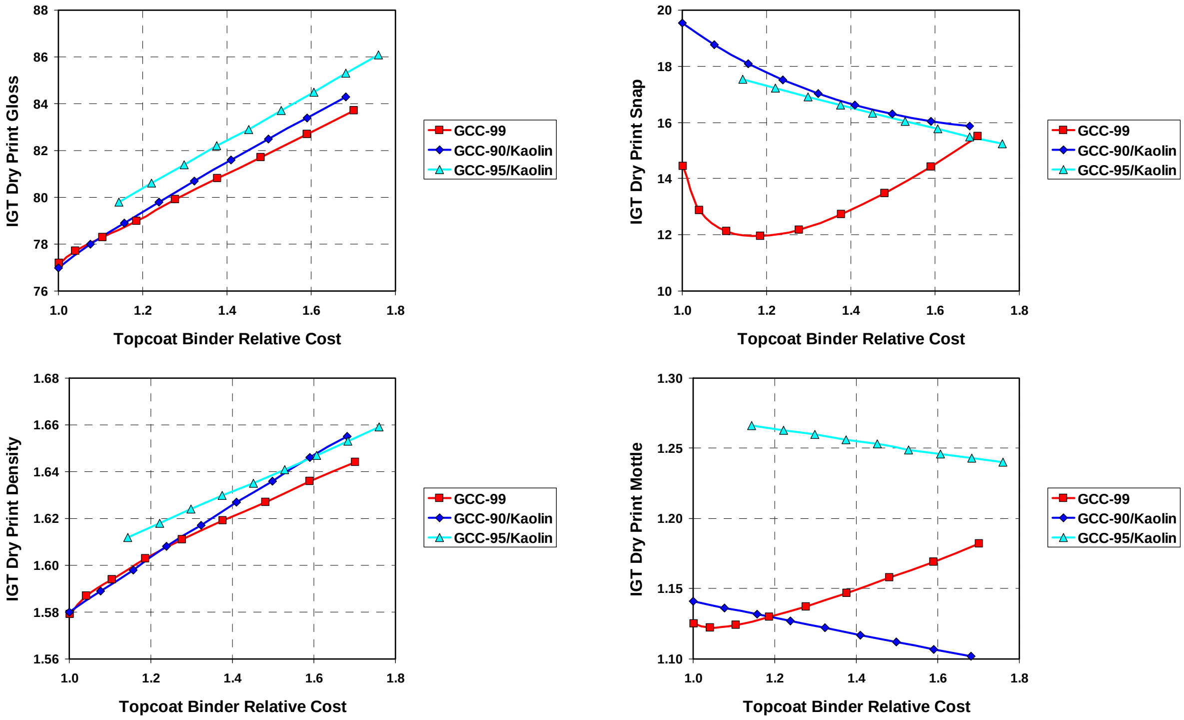

Figure 11: IGT print data with relative topcoat binder costs at the target dry pick value.

Figure 12 shows how the stain area varied with relative binder cost. The stain area increased as relative cost increased (i.e. higher latex levels and lower starch levels). This indicates that the starch tends to produce a more open coating structure and latex the opposite. The GCC-90/Kaolin and GCC-95/Kaolin had higher stain area values compared to the 100% GCC coatings, supporting the view that the coatings containing kaolin had less permeability.

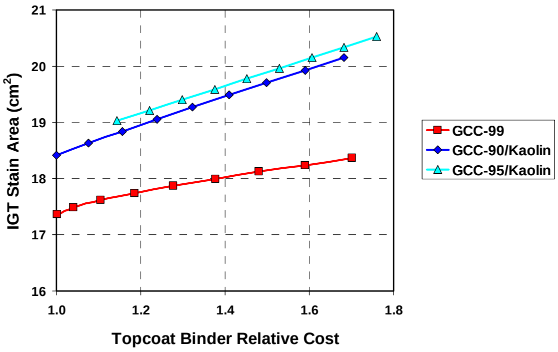

Figure 12: The IGT stain area for each pigment system with relative topcoat binder costs at the target dry pick value.

The wet pick varies, even though the dry pick value is constant, as shown in Figure 13. As the relative binder cost increases, i.e. increasing latex and decreasing starch, the degree of wet pick reduces. It appears that a higher ratio of starch to latex creates a more open, porous coating layer that allows more water or fount solution to penetrate into the coating, thus having a greater weakening effect on the bonds between the binders and pigments.

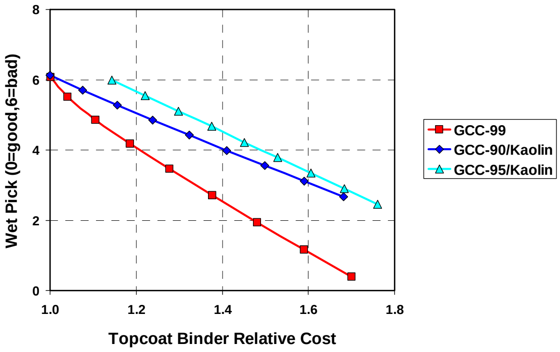

Figure 13: Variation of wet pick with relative top binder costs at the target dry pick value.

DISCUSSION

It is possible to achieve the same printing strength, as measured by dry pick, by using a range of different starch and latex levels in the topcoat. Given that starch usually has a significantly lower price compared to latex, there is an opportunity for cost savings to be made. In this study, between 2 and 10 pph of latex was used and the highest cost topcoat binder combination was ~1.7 times that of the lowest.

The pigments used in the topcoat also had a significant effect on the overall binder demand. The GCC-95/Kaolin blend required more binder (approximately 10% higher binder cost) to achieve the target dry pick strength compared to either the GCC-90/Kaolin blend or GCC-99.

In terms of coating runnability, using more starch and less latex tended to reduce coating solids and low shear (Brookfield) viscosity, but increased the medium shear (Paar Physica) viscosity. More starch also gave the coating formulation better water retention. The different starch to latex ratios seems to have had less effect on coating solids when no kaolin was present. In addition, GCC-99 had lower medium and low shear viscosities, but worse water retention. Using the finer GCC-95 with the kaolin gave lower coating solids, higher medium shear viscosity and better water retention compared to the coarser GCC-90.

The different starch to latex ratios affected standard paper properties. The use of a higher proportion of starch produced lower sheet gloss levels and a less rough coated sheet. The kaolin-free GCC-99 system gave higher gloss levels, especially when a high starch/low latex level was used. The optics of the coated sheets was largely unaffected by the various starch to latex combinations. As expected, the use of kaolin in a topcoat formulation slightly reduced the brightness and whiteness and only a very marginal improvement in opacity.

The variation in the light scatter of the coated sheets indicated that if kaolin was present, there was a slightly different response to the various starch to latex levels, with a small reduction in scatter with an increasing proportion of latex. The opposite occurred when using the kaolin-free GCC-99 pigment system. It is suggested that the SBR latex may have caused some minor flocculation with the ultrafine GCC-99 that is likely to have created some additional structuring in the coating layer. It is also possible that the starch may be interacting more with the kaolin, so reducing the starch and increasing the latex had the effect of creating a more closer packed coating layer.

Light scattering data can be used to calculate a wavelength exponent for the sheets. For traditional commercial coated papers, this gives a relative value for the size of the scatter units in the sheet, with a higher value being given by smaller scatterers. These results indicate that the pore size in the GCC-99 coatings was smaller than that in the kaolin-containing coatings, even though the average particle size was the same as the GCC-95/Kaolin blend. It is likely that the platy kaolin particles have disrupted the particle packing of the blocky GCC-95 particles, thus increasing the size of the pores between the particles. Although it might be expected that the coarser GCC-90/Kaolin blend would have a larger pore size compared to the finer GCC-95/Kaolin blend, it is also possible that the very small kaolin particles are more likely to fit into the pores between the larger GCC-90 particles, thus having less of a disruptive effect, as indicated by the similar wavelength exponent values.

In terms of printability, both print gloss and density increased as the proportion of latex increased, with the GCC-95/Kaolin blend being slightly higher than the other two pigment systems. Print snap is somewhat more complex. When kaolin was present, there was a slow decline with more latex. However, when GGC-99 was used, there was a slightly higher print snap when both very low and high levels of latex were used. The level of print mottle measured by significantly worse for the GCC-95/Kaolin blend. When kaolin was used, print mottle decreased with increasing latex levels, but the opposite occurred for the GCC-99.

The stain area values may be used as an indication of the permeability of the coating, with a larger area meaning a less permeable surface. For all three pigment systems, more latex and less starch meant that the coating became less permeable. The two pigment systems that used kaolin gave significantly higher stain areas compared to GCC-95, supporting the idea that the ultrafine kaolin tends to reduce permeability, through its small particle size (filling in larger coating pores) and its platy particle shape (more tortuous path through the coating for liquid).

The wet pick of the coatings varied, even though the dry pick values were constant. The level of wet pick increased as more starch was present, indicating that the more open, permeable coating layers produced by higher levels of starch allowed more water to penetrate the coating and disrupt the pigment-binder bonding.

SUMMARY

Three different pigment systems have been applied as a topcoat to a commercial precoated woodfree base. It was found that a range of different starch and latex combinations could produce the same printing strength, as measured by their tendency for dry pick. Given that starch usually has a significantly lower price compared to latex, it means that costs may potentially be reduced by moving to a topcoat binder system with an increased proportion of starch. This study indicates that for the same dry pick strength, the relative cost of a latex-rich binder system can be up to 1.7 times that of a starch-rich formulation. However, the use of higher levels of starch can have detrimental effects on coating solids, medium shear viscosity, sheet gloss, smoothness, print gloss, print density and wet pick. Conversely, higher starch can also give better water retention and a reduced low shear viscosity. There were only relatively small differences in optical performance with binder composition.

The three pigment systems used in this study represent some typical approaches to woodfree topcoating, with either fine GCC combined with ultrafine glossing kaolin or 100% ultrafine GCC. A comparison of the GCC-90 with the GCC-95 reveals that less binder was required and hence reduced cost when the coarser GCC was used. In addition, the coarser GCC gave higher coating solids, worse coating retention, lower medium shear viscosity, very slightly lower sheet gloss, slightly higher +UV brightness and whiteness, and significantly less print mottle.

The use of 100% GCC-99 compared to the two blends using kaolin resulted in a similar binder demand (and hence binder cost) as the coarser GCC-90/Kaolin system, reduced low and medium shear viscosity, worse water retention, higher sheet gloss when higher levels of starch were present, smoother paper, higher brightness and whiteness, a smaller coating pore size and a more permeable coating layer, similar print mottle compared to GCC-90/Kaolin and lower wet pick.

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