

Functional Precoats for Multilayer Coating

Chris Nutbeem & Benny Hallam

Asian PaperCon 2010

⊕ KAOLIN

⊕ GCC

⊕ PCC

Functional Precoats for Multilayer Coating

Chris Nutbeem and Benny Hallam

Imerys Minerals Ltd, Par Moor Centre, Par Moor Road,
St Austell, Cornwall PL24 2SQ, UK.

Abstract

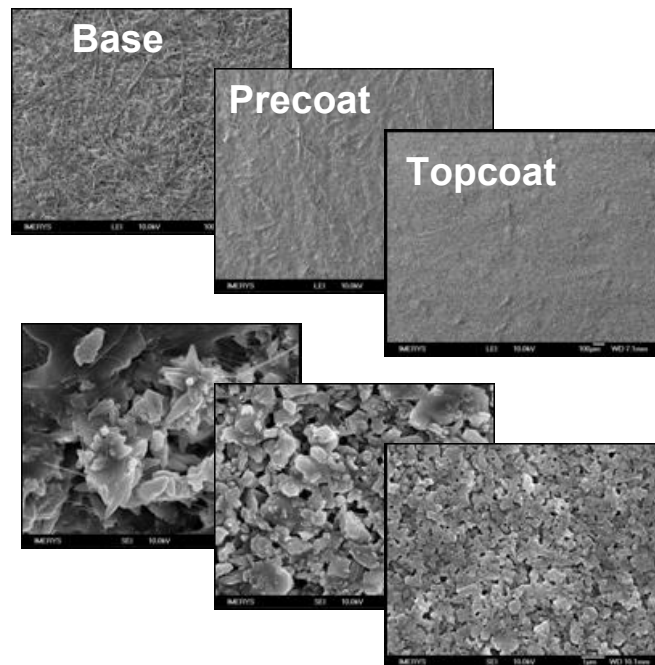
In today's fine paper environment it can be advantageous to use the functionality of kaolin in precoating rather than in topcoating.

In this paper we show how low levels of kaolin can improve precoat coverage and evenness through pilot coater evaluations of different precoat concepts on a fine paper basestock. We go on to explore the impact of precoat design on finished paper properties through a series of laboratory studies in which topcoat pigment selection and formulation was varied. We show that using optimised precoats can give more degrees of freedom in topcoat formulation design for improving quality or reducing cost.

1. Introduction

Much of the coated woodfree produced globally is multi-coated with two or three coating layers applied to each side of the paper. In Europe today there are only a handful of single coated fine paper machines outside the speciality sector, while in Asia multilayer coating is certainly the concept of choice for the newer fine paper lines.

Figure 1. SEM of Woodfree Base, Precoated and Topcoated Paper



In multilayer coating, coverage and performance is built up in layers. The role of the precoat and mid coat layers is principally to provide physical coverage of the base and optical performance, while the role of the topcoat is to produce the desired surface finish (gloss, silk or matt) and printability.

Now, however, cost considerations have become paramount. For example this has led to marked reductions in the amount of narrow particle size distribution (p.s.d.) calcium carbonate used in woodfree precoats for generating light scatter and opacity in lighter weight grades. In the majority of coated fine paper applications today, the precoat is based on 100% coarse, inexpensive carbonate. Likewise topcoat formulations have also been impacted by cost reduction initiatives. In most regions today glossing kaolin is significantly more expensive than standard fine carbonates. As a result there have been clear trends to reduce or eliminate glossing kaolin in topcoating and kaolin-free topcoating concepts have now become well established on many large woodfree machines in Europe and Asia.

Although low-kaolin or kaolin-free topcoating is well established, it is not without its difficulties. Developing sheet gloss and print gloss remains a challenge and often requires significant reformulation in terms of binders and additives. Porosity control and mottle tendency can also be an issue. Often solving these problems can lead to increased formulation costs, which can offset the margins associated with fine kaolin reduction. There is also a risk that a paper's brand image can suffer if printability issues persist.

In many cases, the problems associated with low-kaolin topcoating can be linked to basepaper effects, unevenness in the coating layers and their porosity characteristics. Achieving good basepaper coverage is often central to these issues as is migration of components within the coating layers. In this respect focusing on improving the precoat, rather than the topcoat itself can lead to the best overall solution.

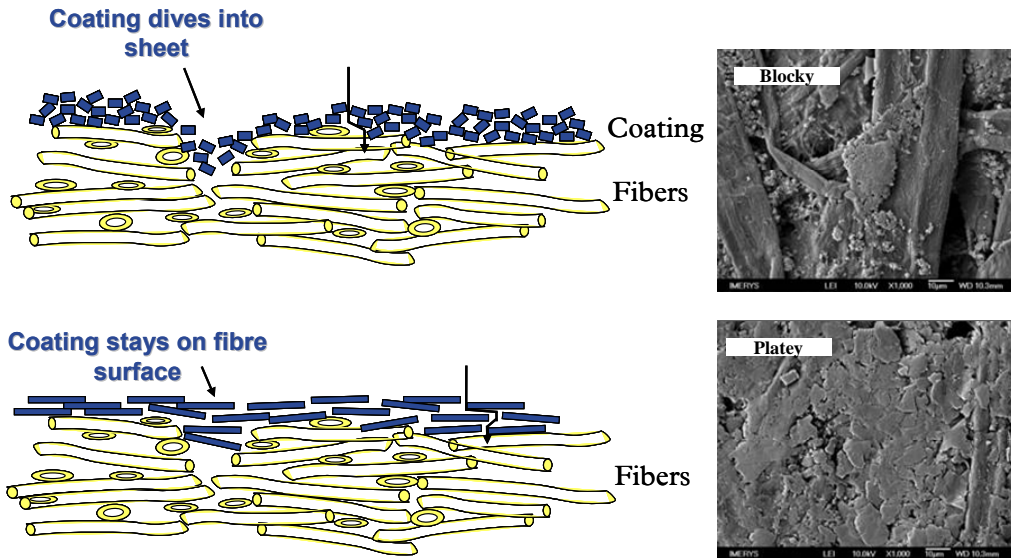
While historically kaolin use in woodfree precoating has been low due to cost and brightness considerations, the development of lower cost, high brightness platey kaolins is changing the dynamic. Already we have seen a growth in kaolin usage in precoating where rougher basesheets are produced and parallels can be drawn with the higher use of kaolin in the board and packaging sector where coverage is paramount.

In today's fine paper environment it may now make more sense from a cost performance standpoint to use the functionality of kaolin in precoating rather than in topcoating.

2. Coverage and Bulking Effects in Precoating

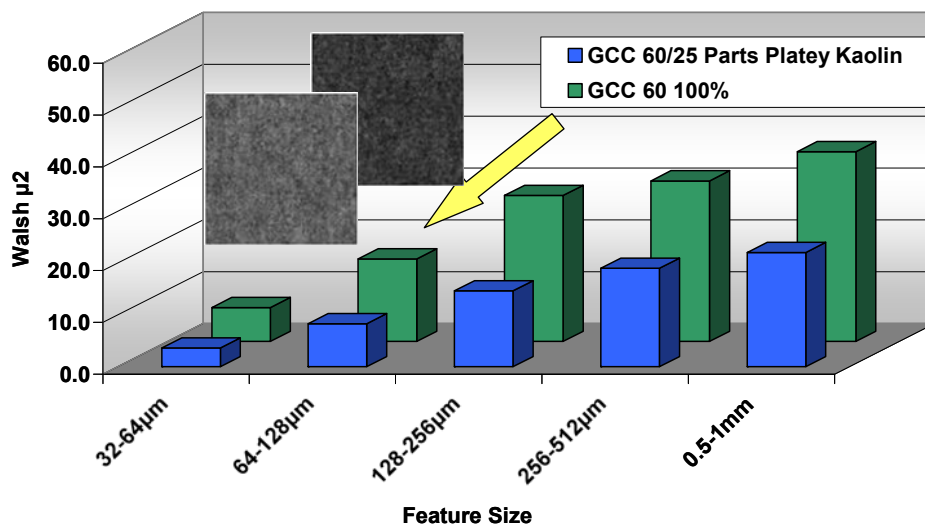
Pigment selection for precoating will certainly have a marked influence on basepaper coverage and its ability to provide a good barrier layer for topcoat application. When considering the coverage and barrier aspects of a precoat it is well known that kaolin can have a significant influence on coverage as illustrated below in Figure 2.

Figure 2. Shape Effects on Coverage



Moreover, these effects can also be seen when the kaolin is used at only a low level in the recipe. This was apparent in a laboratory precoat study carried out on a woodfree basepaper which was known to suffer from poor formation. In this case 25 parts of high aspect ratio Brazilian kaolin was added to a precoat based on coarse GCC. 13 gsm coatings of each pigment system were applied at 1100m/min using a Helicoater™. A latex/starch recipe was used in both cases. The impact on coverage compared to a 100% GCC precoat was investigated using the burnout test and laser profilometry. In the burnout test the paper is soaked in a solution of ammonium chloride and ethanol then heated in an oven so that the fibres darken. Dark areas in the images therefore are indicative of poor basepaper coverage. In laser profilometry, the roughness characteristics of the surface are mapped and then broken down into a series of length scales using Walsh analysis. The plot in Figure 3 shows the Walsh μ_2 value which is a measure of the amount of roughness on a given scale. Burnouts are also shown as insets.

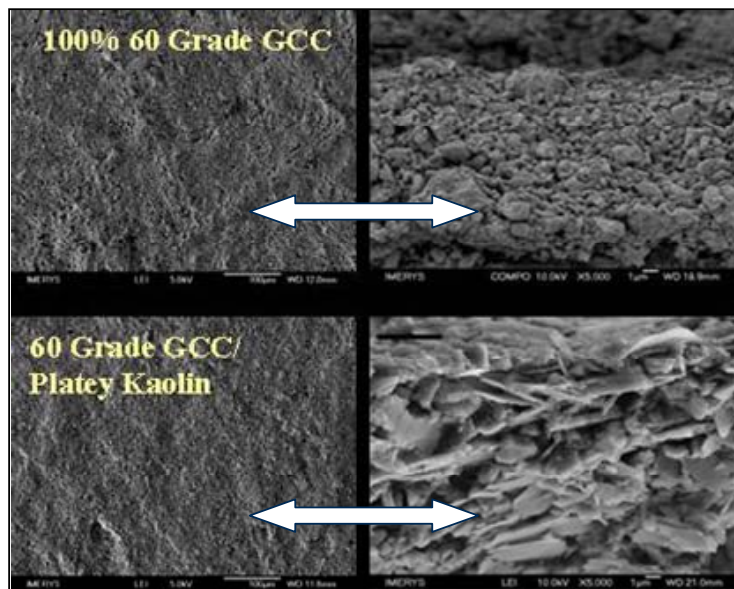
Figure 3. Coverage Effects in Woodfree Precoating



It is clear from these results that roughness on all length scales, including those relating to fibre scale or even formation scale, is reduced through addition of kaolin to the precoat. The burnout images also show that coverage is significantly improved. This can have positive implications for the final paper roughness, gloss and print gloss development and mottle characteristics. Additionally, problems such as fibre pick can also be reduced through improved coverage. This can have benefits for paper machine runnability and efficiency and can also offset the need for increased binder in the coating.

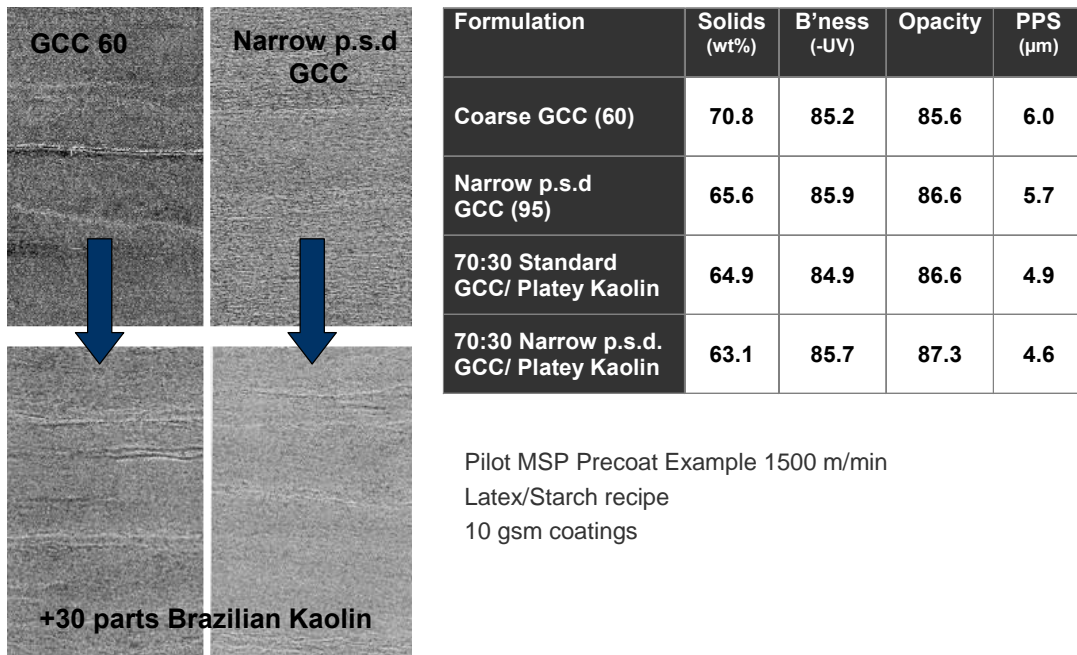
In addition to the coverage aspects, high aspect ratio kaolins can also give a bulky structure when combined with GCC. This will further improve coverage, but also improve optical performance through increased light scattering. As a result, it can often provide better hiding of a mottled base which is a significant benefit in the board and packaging sector. However, the structure will also retain a high degree of tortuosity making fluid flow and migration of topcoat binders more difficult. This is illustrated below in Figure 4 which shows surface and cross-sectional SEMs of precoats based on 100% coarse GCC and coarse GCC combined with 50 parts of high aspect ratio kaolin.

Figure 4. Bulking Effects of High Shape Kaolin and GCC



The optical and coverage benefits associated with combinations of kaolin and GCC were very evident in a woodfree metered size press precoat study which was carried out at pilot scale (Figure 5). Inclusion of 30 parts of kaolin in the precoat gave much improved coverage when to either standard or narrow p.s.d. (engineered) GCC. The results showed significantly improved smoothness in the precoated paper even though the applied coating solids were lower. The structuring effect was also evident when assessing the balance between brightness and opacity. Kaolin addition to standard GCC had only a minor impact on brightness but increased opacity by 1 unit. Similar effects were also seen when kaolin was added to narrow p.s.d. carbonate. However, one telling comparison is that of standard GCC and kaolin with 100% steep carbonate. In this case it is evident that the recipe with kaolin gives much better coverage and smoothness and similar opacity to the engineered carbonate with only 1 unit lower brightness. The improved coverage and smoothness may enable kaolin to be reduced in topcoating while still maintaining gloss targets. This would likely compensate for the brightness loss and further lower the pigment cost across both coating layers.

Figure 5. Coverage and Optical Effects in MSP Precoating



So in summary it is apparent that kaolin use in the precoat can improve coverage significantly compared to 100% carbonate based precoat. The key to the improved coverage lies in the aspect ratio of the kaolin, with higher shape kaolins better than lower shape kaolins. An additional benefit is the structuring effect of kaolin and GCC which increases precoat bulk, coverage and optical properties and goes some way towards matching the performance of engineered carbonates. However, these conclusions are based on a range of generic studies each of which was limited in scope. Recent work has therefore focussed on more systematic studies at pilot and laboratory scale to try to understand how kaolin choice influences performance in precoating when used at a common (low) level in the recipe and how this can effect the finished paper quality in both gloss and matt applications.

3. Pilot Coater Precoating Studies

A pilot coating study was conducted at KCL in Finland to assess precoat kaolin options when used as a low level blend component with GCC (60<2µm GCC was used). Blade coating onto a European woodfree basepaper was carried out at 1200m/min using a jet applicator to give coatweights of 9gsm to the topside. The back side in all cases was coated with a 100% reference GCC formulation. The kaolin options were carefully selected with a view to giving good physical coverage of the base sheet even at low addition. Pigment and formulation details are shown in Figure 6 and Table 1 below.

Figure 6. Precoat Kaolin Properties

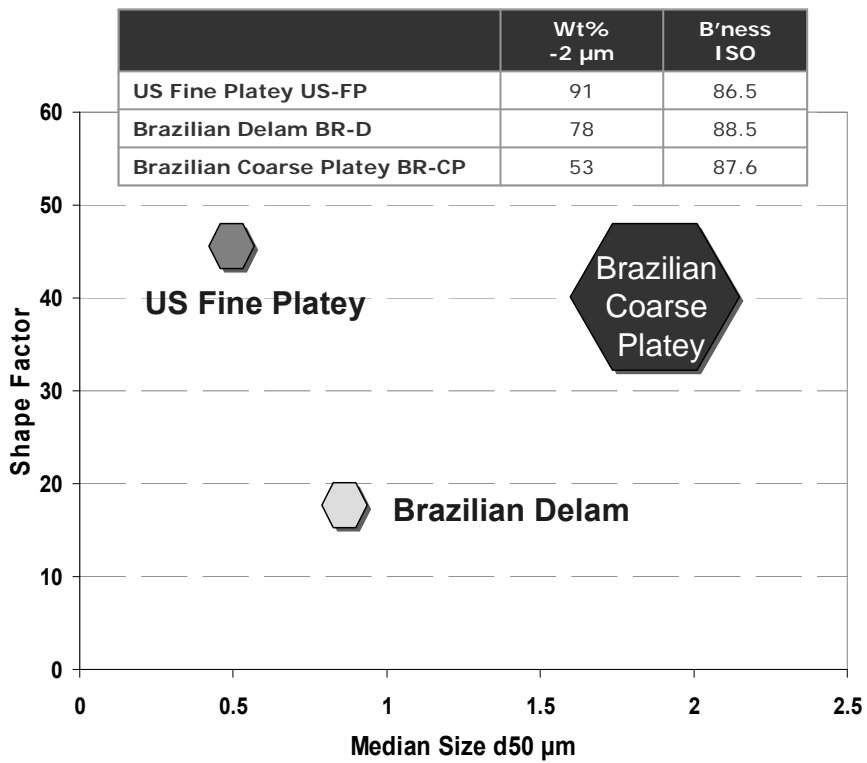
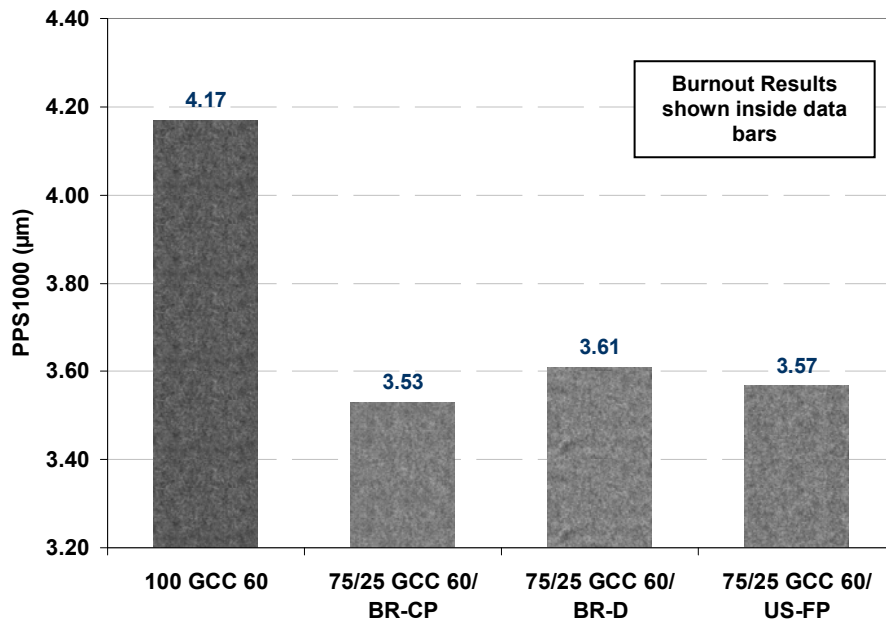


Table 1. Formulation Details for Pilot Precoating

	1	2	3	4
US Fine Platey US-FP				25.0
Brazilian Delam BR-D			25.0	
Coarse Platey Brazilian BR-CP		25.0		
GCC 60	100.0	75.0	75.0	75.0
Starch	6.0	6.0	6.0	6.0
Latex	6.0	6.0	6.0	6.0
Cross-linker	0.3	0.3	0.3	0.3
Colour Solids %	66.5	65.0	65.5	64.0

The pilot precoated papers were characterised in terms of their roughness and the extent to which the coatings had covered the base paper. Figure 7 shows that the overall PPS values are improved when any of the kaolins are added to the precoat. This was also evident in the burnout tests which showed that the darkened fibres were much less evident through the kaolin-containing precoats.

Figure 7: Coverage and Smoothness after Precoating



Further analysis sought to show how roughness was influenced on different length scales and how coating thickness was influenced by the precoat selection. The results shown in Figures 8 and 9 clearly show that the kaolin containing precoats reduce roughness at fibre length scales and that the bulkier nature of the coating has lead to improved coating thickness as measured by optical microscopy.

Figures 8: Roughness on Different Length Scales

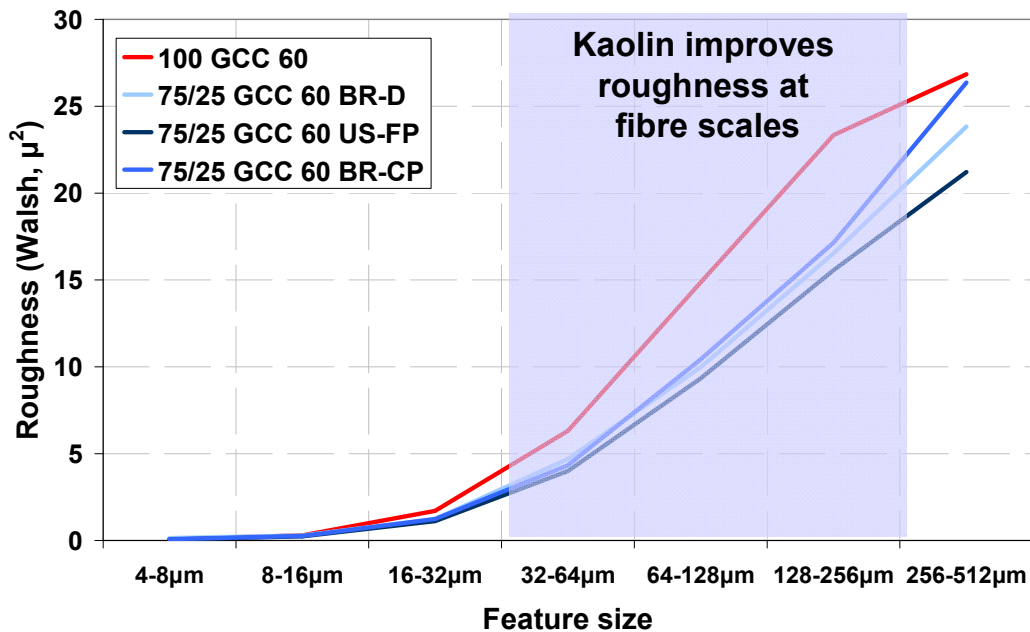
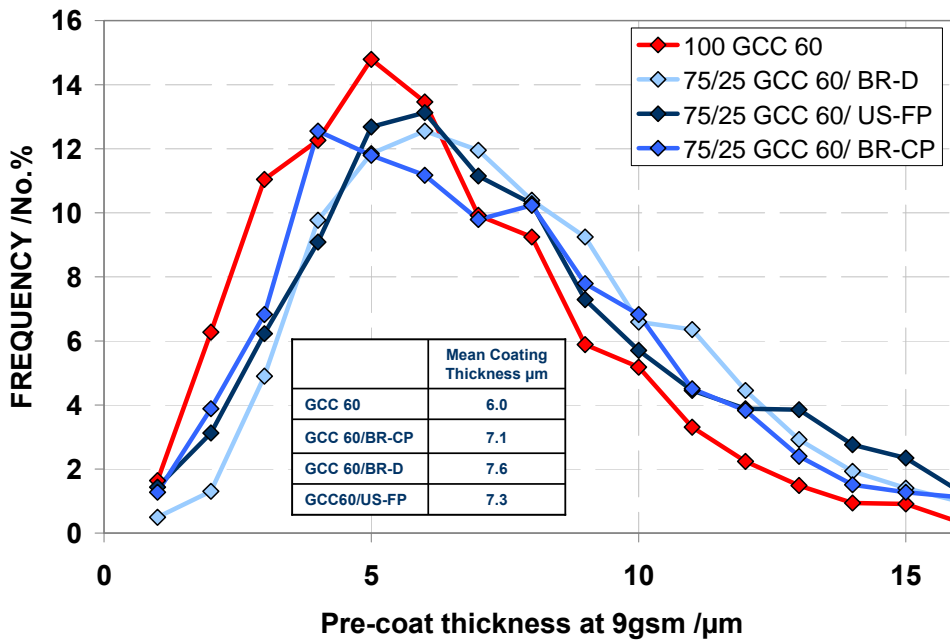


Figure 9: Coating Thickness Distribution

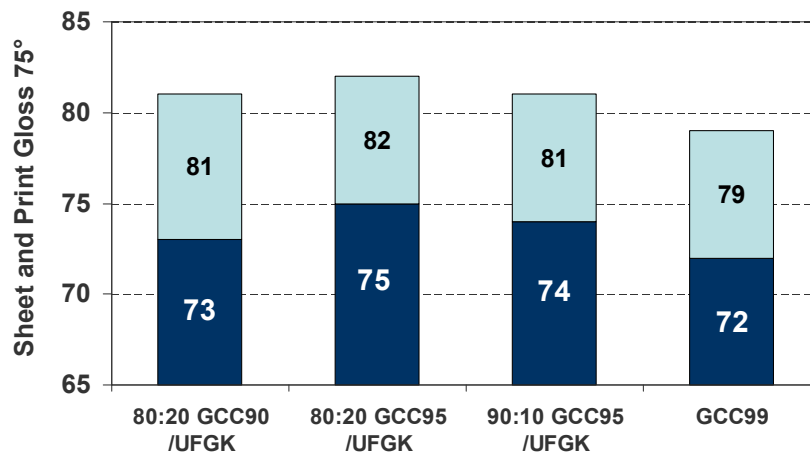


Overall, the results for these pilot precoating studies were consistent with what had been observed earlier and showed categorically that low levels of kaolin in the precoat can give significant benefits to basepaper coverage.

4. Influence of Precoat in Glossy Woodfree

As discussed earlier, kaolin-free topcoats have become well established in multilayer coating applications. However, in many situations the degrees of freedom for using kaolin free topcoats can be limited. Paper and print gloss development remain the key challenges with these systems. This can be seen in the following woodfree example where typical fine paper topcoating recipes based on 90 and 95 grade GCCs and ultrafine glossing kaolin were compared with 100% ultrafine GCC. In this study the binder and thickener systems (latex/CMC) were kept constant for all points. Results below all refer to 11gsm coatweights

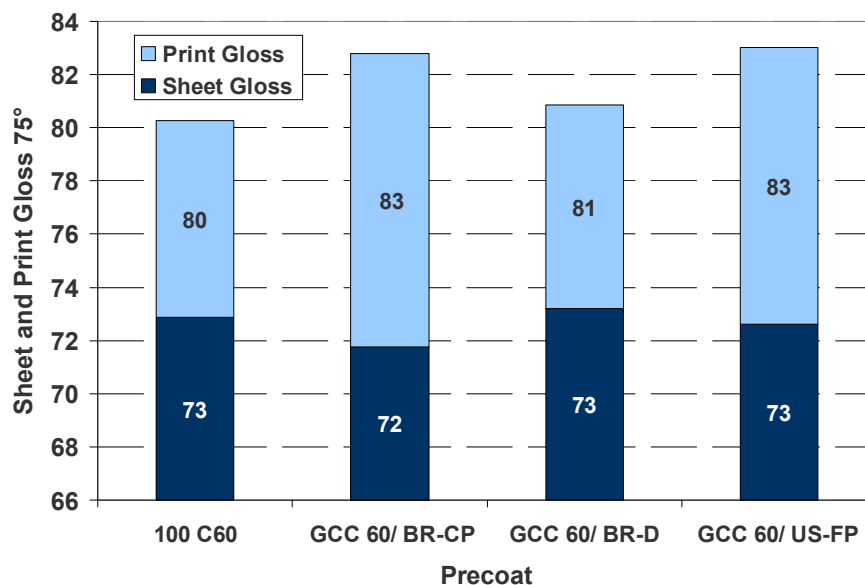
Figure 10: Gloss and Print Gloss of Topcoat Concepts



It is clear from this data that in the absence of formulation optimisation, the 100% GCC topcoat remains slightly deficient in sheet gloss and print gloss compared to standard approaches. Increasing the sheet and print gloss in the kaolin free systems can often mean changing to finer binders with lower ink interactivity while also increasing calendar load which can be detrimental to opacity and stiffness.

In the current study the influence of modifying the precoat on the performance of a kaolin free topcoat was explored using the precoated basepapers described in Section 3. The topcoat recipe evaluated consisted of 100 parts Ultrafine GCC, 10 parts SB latex, 0.2 parts CMC with some lubricant and immobiliser. Coatings were applied at 69% solids in the laboratory using a Helicoater™ at 1000 m/min to give 11 gsm coatweights. The resulting coated papers were then laboratory supercalendered to give gloss levels for the all carbonate reference of close to 75.

Figure 11: Effect of Precoat on Gloss and Print Gloss of Kaolin Free-Topcoat

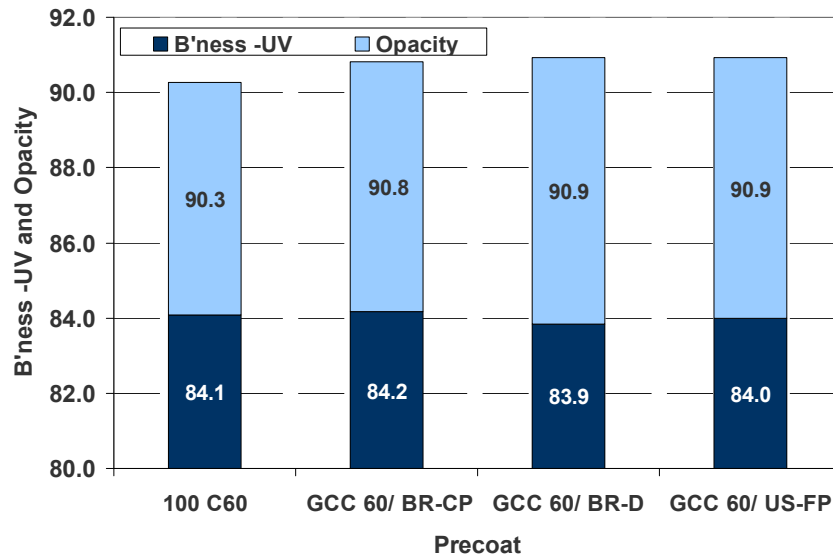


The results from this study showed that while using low levels of kaolin in the precoat had relatively little influence on the sheet gloss, there were clear benefits to print gloss. This was especially true when the precoat contained the highest aspect ratio kaolins. In some respects these results were surprising given that the basepaper used for this work was relatively smooth with a PPS 10 of only 5.6 µm before precoating. On rougher base stocks we might expect even bigger differences to be seen from adding kaolin to the precoat.

Opacity and brightness considerations are also important in coated woodfree applications. In general reducing kaolin in topcoat can be detrimental to opacity, especially if harder calendering is required to restore gloss. In this work we have seen that adding low levels of kaolin to the precoat has relatively little impact on finished paper brightness after application of the topcoat (Figure 12). This is in part due to bulk structuring (as discussed earlier) resulting in improved light scatter. This also has implications for opacity and in this work we saw close to 0.5 units increase in the finished paper from kaolin addition in the precoat. While this in itself is beneficial, as many fine papers, especially at the lighter grammages are limited in opacity, it also gives more degrees of freedom for adjusting calendering to regain gloss.

One point to note, however, is that while non-UV brightness is largely unaffected from kaolin in the precoat fluorescence can be reduced resulting in lower overall UV Brightness. That said, this drop is more than offset by kaolin removal from the topcoat and could also be adjusted through changing the balance between OBA in pre and topcoat.

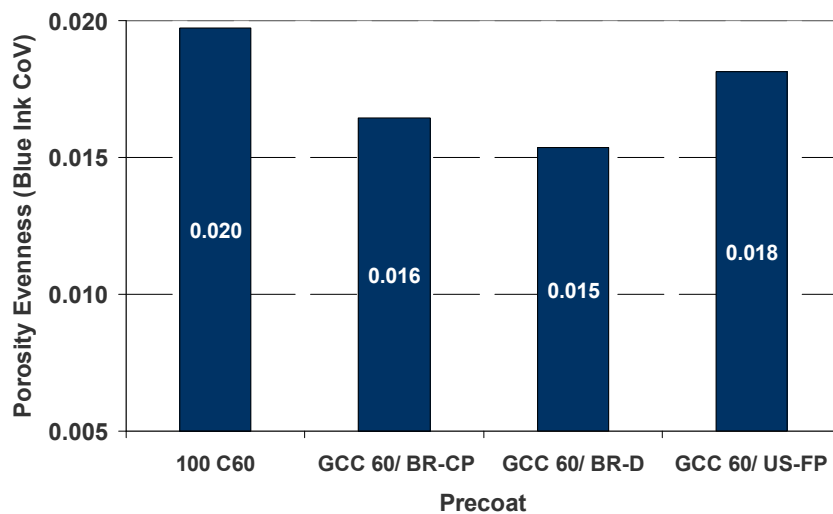
Figure 12: Effect of Precoat on Brightness and Opacity of Kaolin Free-Topcoat



A common issue cited in many coating applications is the presence of mottle. This may relate to unevenness in porosity in the coating layers or may again be due to poor coverage of basepaper unevenness. In this work we looked at the evenness of the porosity characteristics in the topcoat using an ink penetration method. Blue ink was applied to the paper with a motorised bench top blade coater so that ink which did not penetrate the surface was quickly removed by the metering blade. The resulting printed paper was then analysed for porosity evenness using image analysis techniques to assess the coefficient of variance in the print density.

The results in Figure 13 show some benefits in terms of topcoat porosity evenness from adding kaolin in the precoat. The effects were most pronounced with the Brazilian kaolins and it might be expected that this could lead to a lower tendency for porosity related mottle such as secondary or backtrap mottle.

Figure 13: Effect of Precoat on Porosity Evenness



Mottle effects in relation to precoat selection were further assessed in a separate study on another coated woodfree basepaper with a PPS 10 roughness of 6.4 which was known to suffer from formation issues leading to gloss mottle in the finished paper. In this case the same high shape kaolins (Br-CP and US-FP) as described in Section 3 were applied at 25% level to a precoat recipe based on 60 grade GCC. Precoats were applied at 1100 m/min to give coatweights of 13 gsm. A latex-starch recipe was used and colour solids of 67% were maintained throughout. Topcoating was then carried out using a small motorised, bench top coating apparatus. A standard topcoat based on 95 grade GCC and 23 parts of glossing kaolin was used.

Once again it was evident that the precoat containing 25 parts of the two kaolins gave significantly better coverage than the 100% GCC based precoat. This was seen through burnout analysis and again through coating thickness distributions based on SEM cross-sections. These are shown in Figure 14 and it is evident that in this case kaolin addition to the precoat has lead to a 20% increase in coating thickness.

Analysis of the finished papers focussed on determining whether gloss mottle arising from the base had been reduced as a result of the improved precoat coverage. Gloss mapping was carried out using a laser reflectometer. The gloss map generated was then converted to a greyscale image and a Fast Fourier Transform applied to provide information about the scale of variation across the surface. The results are shown in Figure 15 where the original image has been broken down into a series images relating to variation on different length scales. The results show that the most variation or mottle occurs over scales between 0.5 and 4mm which relates to fibre and formation effects. It is also clear that while kaolin addition to the precoat has not totally eliminated this mottle pattern it has been significantly reduced in both cases (as can be quantified by a lower coefficient of variance [COV]).

Figure 14: Coating Thickness and Coverage

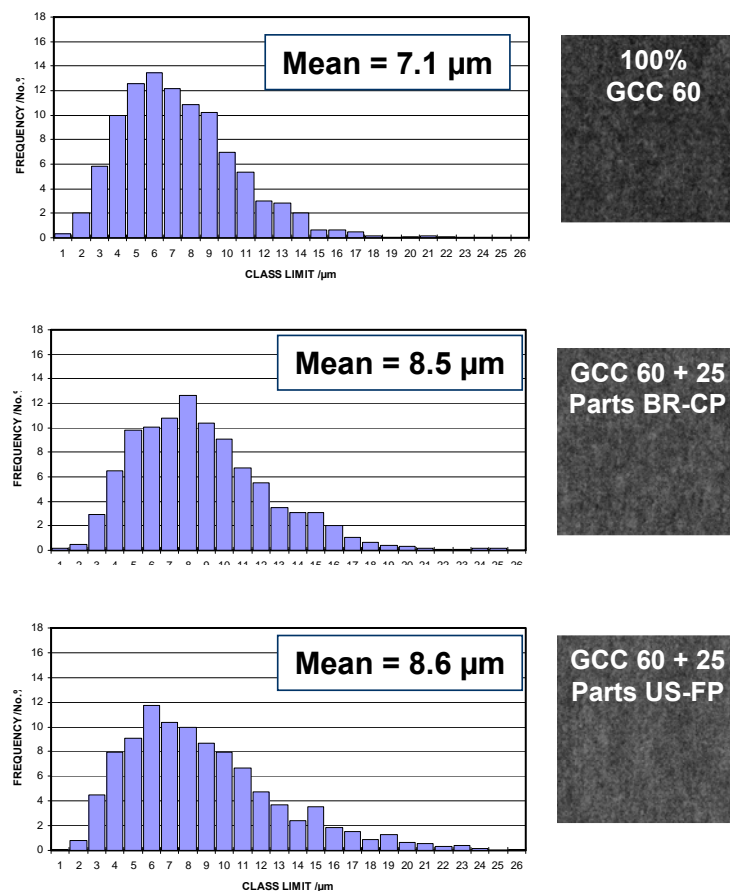
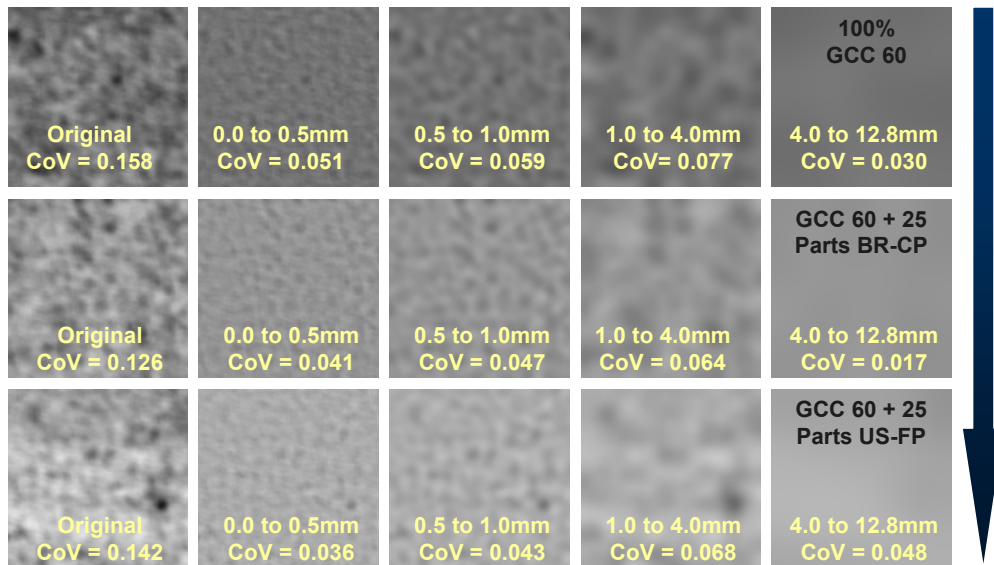


Figure 15: Gloss Mottle Analysis



In summary, replacing kaolin in topcoating with 100% GCC is often detrimental to gloss, opacity, and print gloss. If in contrast, the use of coarser, platier kaolin into the precoat allows the opacity and print gloss deficits to be overcome. This enables more degrees of freedom for calender optimisation or formulation optimisation (reduced binder, co-binder etc) to recoup lost gloss. The effect of kaolin in precoat is likely to be greatest on rougher basestocks where coverage effects can still influence gloss and evenness even after topcoating. Likewise, in any situation where unevenness in the base exists leading to mottle, high shape kaolin addition to the precoat can be a useful tool for improving the situation.

5. Influence of Precoat in Matt/Silk Woodfree

Producing matt and silk papers is often a complex juggling act of many (often competing) paper characteristics. However, in general the key compromises faced by matt/silk producers are achieving good smoothness together with low paper gloss and high bulk. Achieving high print snap or delta gloss without unacceptably slow ink setting is also very important. This latter issue is a particular problem in matt papers where the pore structure in the coatings often consists of low numbers of larger pores which may have insufficient capillary suction to initiate a phase separation of solvent from the ink. The result can be very long drying times leading to ink scuff problems and reduced efficiency at printing presses (longer work and turn).

In this study we wanted to see if modifying the precoat can influence the gloss-smoothness balance in low gloss applications leading to improved delta gloss without slowing ink setting rates. It was also evident from the outset that the type of coarse high shape kaolin used in precoating could also have value for controlling gloss, smoothness and printability in matt/silk coating.

As before, pilot coated basepapers based on 100% 60 grade GCC and 60 grade GCC with 25% coarse platy Brazilian kaolin (as described in Section 3) were used to map out these effects. However, in addition to applying a standard kaolin-free bi-modal topcoat, an additional point was included in which some of the coarse carbonate used to control gloss in the topcoat was replaced with the same high shape kaolin as was used in the precoat. The trial matrix is described below in Table 2.

Table 2. Matt/Silk Study Trial Plan

Precoat	P1	P2	P2
GCC 60<2 μ m (C60)	100	75	75
Brazilian Coarse Platey BR-CP		25	25
Starch	6	6	6
SB Latex	6	6	6
Cross-linker	0.3	0.3	0.3
Target coatweight (gsm)	9.0	9.0	9.0
Topcoat	T1	T1	T2
GCC99	60	60	60
GCC60	40	40	20
Brazilian Coarse Platey BR-CP			20
SB Latex	10	10	10
Imobilizer	0.1	0.1	0.1
Lubricant	0.8	0.8	0.8
Thickener	0.2	0.2	0.2
Application solids (wt%)	70	70	70
Coatweight gsm	11	11	11

The coated papers were very lightly calendered to achieve a target gloss level of close to 40. Paper and print properties at constant gloss were then determined. Results are shown below in Table 3 and key properties graphically in Figures 16 and 17.

Table 3. Paper and Print Properties at Constant Paper Gloss

Precoat	P1	P2	P2
GCC 60<2 μ m (C60)	100	75	75
Brazilian Coarse Platey BR-CP		25	25
Topcoat	T1	T1	T2
GCC99	60	60	60
GCC60	40	40	20
Brazilian Coarse Platey BR-CP			20
Results at 40 Gloss			
Bulk (cm ³ /g)	0.92	0.90	0.90
PPS1000 (μ m)	1.99	1.55	1.47
Brightness (D65/10)	84.5	84.4	84.1
Opacity (D65/10)	91.3	91.5	91.8
Delta gloss	17	20	26
Print density	1.55	1.55	1.57
Print abrasion	6.0	6.1	5.0
Set-off density at 30 sec	0.10	0.09	0.09

Figure 16: PPS Roughness at Constant Paper Gloss

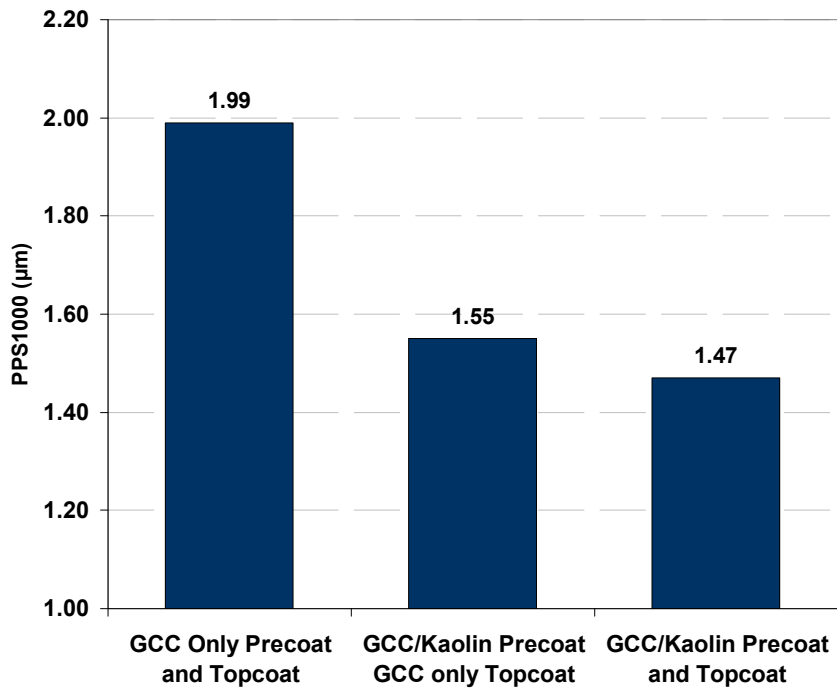
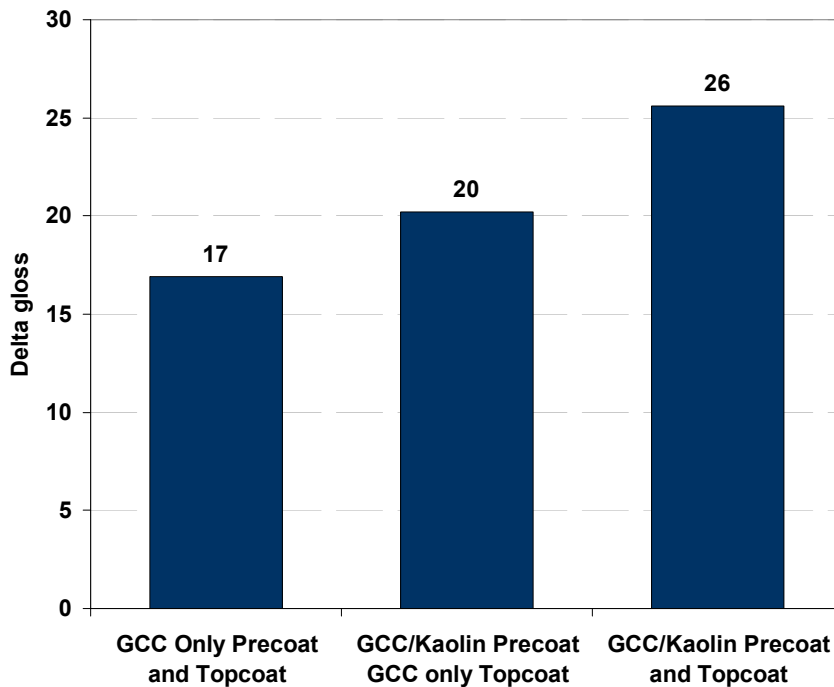


Figure 17: Delta Gloss at Constant Paper Gloss



In assessing the results it is clear that using coarse high shape kaolin is beneficial in matt/silk performance. When added to the precoat, the result is improved smoothness for the same paper gloss level and improved print gloss development (delta gloss) without any adverse change in ink setting rate (see table 3). It was also apparent that further benefits can be seen when the same coarse kaolin is used to partially replace the coarse carbonate used in the

bimodal low gloss topcoat. In this case significant improvements in delta gloss were seen together with improvements in print abrasion (ink scuff) and opacity. Once again paper gloss levels and ink setting rates were maintained at a level similar to the all carbonate reference.

Overall, this study has shown that addition of coarse platey kaolin to the precoat is good for providing low sheet roughness for a given target gloss which helps with print gloss development. Furthermore, these types of kaolins are also very effective in the topcoat layer to give further improvements in printability.

6. Overall Summary and Conclusions

In these studies we have seen that using kaolin together with coarse carbonate in precoating applications can have a significant impact on the ability of the precoat to cover the roughness characteristics of the basepaper. Selecting kaolins which are relatively coarse in particle size and have high aspect ratios and hence large plate diameters are key to making this approach successful. In this work we have focussed on commercial kaolins from North America and Brazil, however, there are also select kaolin reserves in Asia which could, with the appropriate processing and know how, provide the necessary characteristics for successful precoating applications.

Good basepaper coverage is essential in maintaining quality in multi-layer coating applications and can also offer potential for cost reduction. For example improved coverage could enable the use of lower cost rougher base stocks without the same tendency for mottle related issues. Additionally, improved precoat coverage can facilitate the use of kaolin free topcoats especially on rougher basestocks. This can bring value in many ways. In essence we are replacing high cost ultrafine glossing kaolin with lower cost precoating kaolin. In replacing the topcoat kaolin there are often benefits in terms of topcoat binder reduction, (typically 1-2 parts reduction) which will yield significant savings. We have also seen that kaolin in precoating improves print gloss with kaolin-free topcoats. This may offset the need for more expensive binders to control printability thus further increasing the cost savings with kaolin-free topcoating.

Additionally we have seen quality benefits in matt or silk grades where coarse platey kaolin in the precoat helps smoothness and delta gloss with further benefits coming from using the same kaolin to replace some coarse GCC in the topcoat. While this approach does not reduce the overall formulation cost for the coatings, it would do much to improve the market perception of the paper as these are key indicators of quality.

Overall it is evident that while carbonates can be made fine enough to deliver gloss they cannot be modified sufficiently in shape to improve coverage. As a result, we conclude that the value of kaolin in today's cost focussed coated fine paper market is therefore in its ability to cover the surface, not in its ability to generate paper gloss.



✦ **Europe**
Tel: +44 1726 818000

✦ **Asia Pacific**
Tel: +65 67 99 60 60

✦ **N. America**
Tel: +1 770 594 0660

✦ **S. America**
Tel: +55 11 2133 0055

Email
paper@imerys.com