Factors governing print performance in offset printing of matte papers

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ABSTRACT

Matte and low gloss papers form a significant, increasing segment of the coated paper sector because they provide less glare and easy readability. Pigment blends are necessary for the desired balance of properties. The authors present a new approach to matte pigment design using bimodal blends of coarse and ultrafine components. A new pigment system can give an improved balance of properties resulting in improved print abrasion or improved brightness without affecting sheet gloss or print performance. The new pigment system requires tailoring for particular applications. Single coated paper will require a different pigment and binder package compared with a double coated paper.

Application:

A newly designed pigment gives significantly different paper and printing properties for producing matte coated papers.

In North America, matte and low gloss paper comprise about 25% of coated paper production. In Europe, this market sector is approximately 50%. Matte papers therefore are a significant, growing proportion of coated paper production. The most important criterion for a matte paper is good printability with high delta gloss, i.e., printing sheet gloss. In Europe, semi-matte/silk/satin sheet grades often have sheet gloss values of 25-35 with a delta gloss above 30. Matte paper in North America has a gloss level below 33. These papers usually have delta glosses of 20–30. The levels of print abrasion common in both market areas are high at 3–4. Many printed matt papers use a varnish to eliminate this problem.

DESIGN OF A MATTE PAPER

To achieve the levels of sheet gloss, a paper must have a degree of roughness sufficient to scatter rather than reflect light. One can consider a paper as containing two types of roughness both of which can affect gloss *(1, 2)*. Base paper fibers and formation influence large scale or macro roughness. Micro roughness is small scale and originates in the size, shape, and orientation of pigment particles on the surface. A true matte sheet requires macro and micro roughness for sheet gloss levels below 10. To obtain commercial sheet gloss levels below 33, a combination of roughness is necessary. **Figure 1** shows that a sheet can be macro rough and micro smooth or macro smooth and micro rough. If a sheet were micro and macro smooth, it would have very high sheet gloss.

Two commercial methods produce a semi-matte sheet:

- Using fine pigments with very little or no calendering, i.e., micro smooth and macro rough
- Using coarse pigments with calendering, i.e., micro rough and macro smooth.

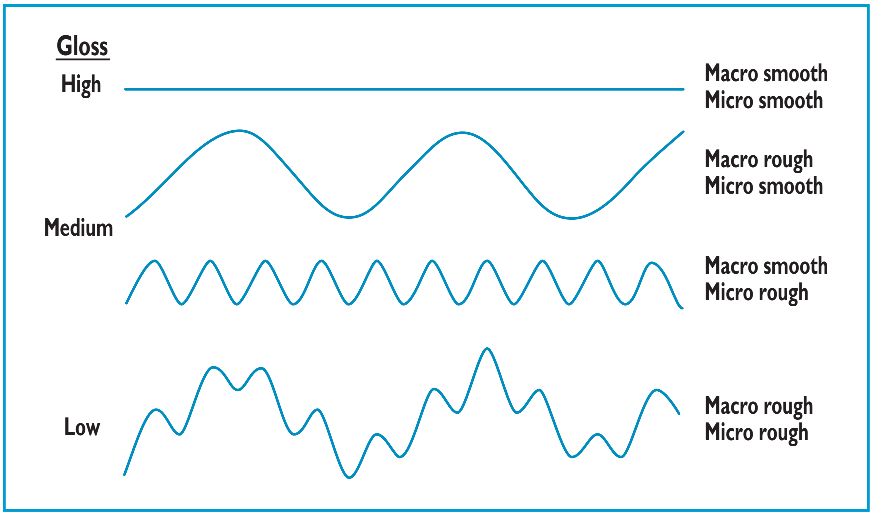
Both methods have potential disadvantages:

- Paper made with an uncalendered coating of fine pigments is very susceptible to marking since the glossing potential of fine pigments is very high. Since the paper is uncalendered, retaining a high degree of macro roughness is likely.
- Conversely, paper made with a coating of coarse pigments that has been calendered will be macro smooth. The coarse nature of the pigments will probably cause some printing problems such as low print gloss and high print abrasion.

This study tested a wide range of commercially available papers to determine how paper and print properties vary with sheet gloss. Several obvious trends are evident in the results:

- Paper roughness decreases with increasing sheet gloss as **Fig. 2** shows.
- Print gloss increases with a smoother and more glossy sheet as **Fig. 3** shows.
- Print abrasion decreases with a smoother and more glossy sheet as **Fig. 4** shows.
- No general correlation exists between paper brightness and gloss or roughness as **Fig. 5** shows.

Traditionally, production of matte papers has used a balance between sheet brightness, delta gloss, and print abrasion or print scuff. A high level of ground calcium carbonate (GCC) gives high sheet brightness but poor delta gloss and print abrasion as **Fig. 6** shows schematically. Conversely, a high amount of clay in the coating gives good delta gloss and low print abrasion but poor



1. Idealized paper surfaces2. Roughness vs. gloss for commercial paper samples

sheet brightness. Ideally, a matte coating system should produce a high brightness coating with good delta gloss and low print abrasion. More practically, two possible targets are a paper that has the same printing performance but improved sheet brightness and a paper that has the same sheet brightness but improved printing properties as **Fig. 7** shows.

Development of a new approach allows manipulation of the coating structure to provide the benefits of fine pigments—high print gloss and low print abrasion—without the problems of sheet marking. A blend of pigments makes a structure that is rigid and can be calendered without generating high levels of sheet gloss.

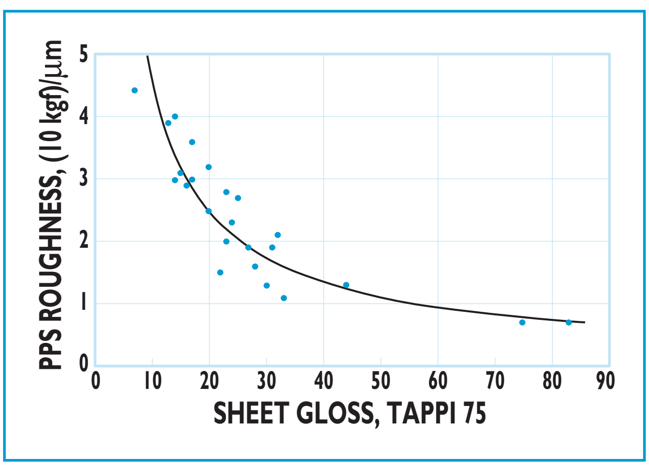
A coarse, blocky pigment is a "spacer" to produce a layer that is very resistant to calendering. The only way to improve the smoothness of these particles is to crush them! An ultrafine pigment fills between these large particles. During the calendering process, the large particles prevent the sections of the coating containing the ultrafine particles from compacting. **Figure 8** shows this coating structure.

The result of calendering this coating structure is reduction of the macro roughness without generating excessive micro smoothness from the particles. The portions of the coating with the ultrafine pigments behave as though they are uncalendered with the coarse particles preventing marking.

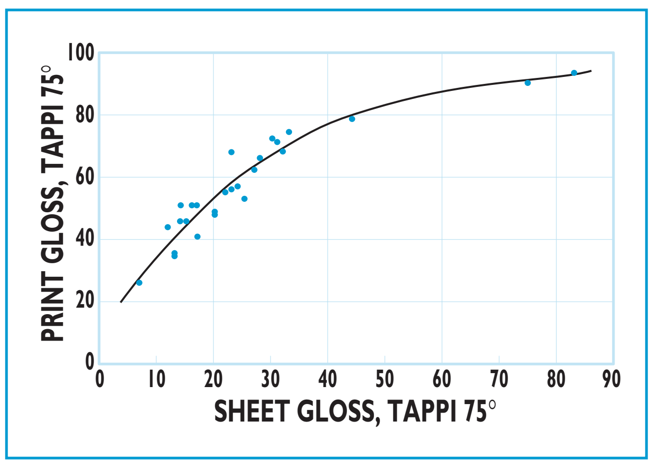
This pigment system can be very sensitive to the ratios of the two components used:

- With excessive coarse pigment, the holes between the coarse particles will not fill completely, and the sheet will have high abrasion and low print gloss.
- If too little coarse pigment exists, it will be unable to prevent the ultrafine pigment being calendered with resultant generation of excessive sheet gloss.

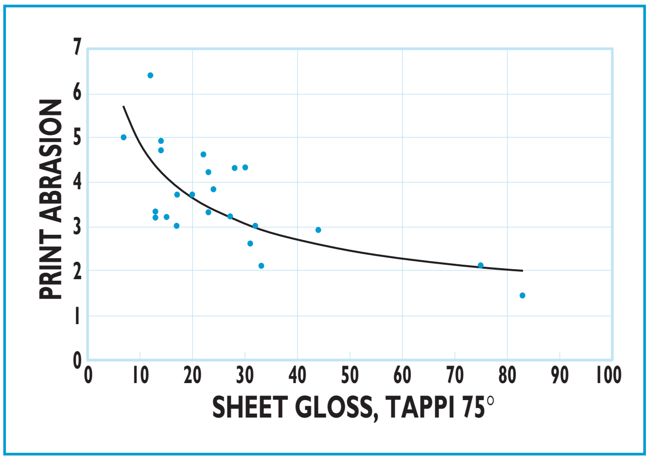
Conceptually, the simplest method of producing a mixture of coarse and ultrafine material is to mix two separate steep particle size distributions (PSD). The coarse end should ideally have particles 2–4 µm. The ultrafine fraction should be 0.1–0.5 µm. A logarithmic normal distribution can approximate the particle size distribution of a pigment as **Fig. 9** shows. A median particle size and a width parameter are necessary to specify distribution shape:



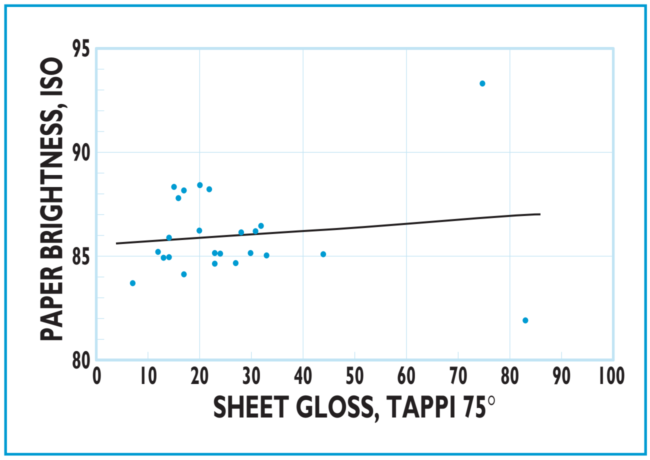
2. Roughness vs. gloss for commercial paper samples



3. Print gloss vs. sheet gloss for commercial paper samples



4. Print abrasion vs. gloss for commercial paper samples



5. Brightness vs. gloss for commercial paper samples

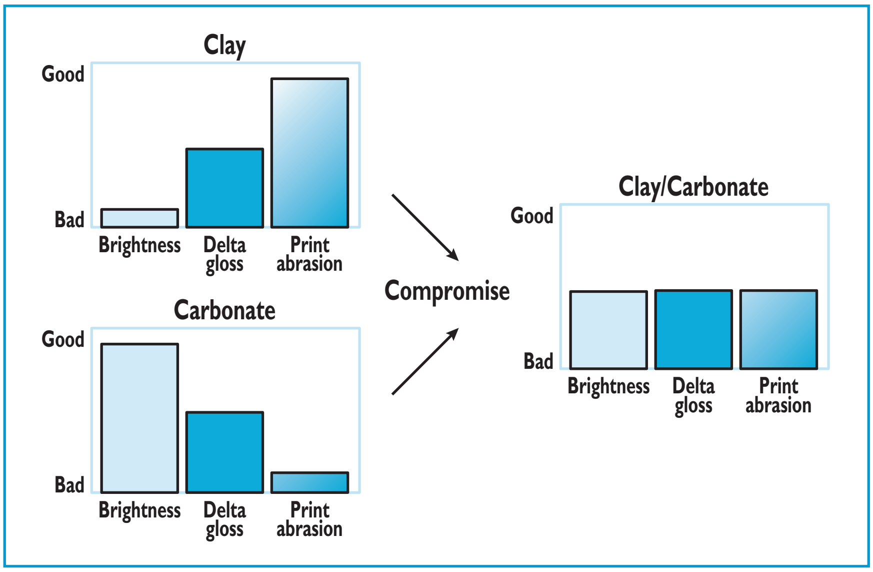
$$\text{Frequency} = \{1/[x\sigma(2\pi)^{1/2}]\}\exp -[\log (x/m)]^2/2\sigma^2 \quad (1)$$

where

m = median of the distribution
σ = width of the distribution
x = particle size.

Practical considerations impose limits on the size distribution. If the coarse end was more coarse, excessive problems would occur with coating such as scratches, streaks, etc. If the ultrafine end was more fine, an excessive demand for chemicals would exist due to a very high surface area (high dispersant demand, high binder demand, etc.). The practical approach to producing the new pigment design is to use mixtures of products that match the particle size considerations outlined above. As an example, approximately equal amounts of the coarse and ultrafine material would produce a typical "bimodal" PSD. In this case, it would have less material with a size of about 1.0 µm as **Fig. 10** shows. Many experiments have shown that good performance requires meeting the following equation with a width distribution, σ, less than one (3):

Degree of bimodality = $\log_{10}$(median size coarse pigment) – $\log_{10}$(median size fine pigment) > 0.6 (2)



6. Influence of coating pigment on matte paper properties

The studies reported here focused on using a GCC as the coarse fraction and two types of bimodal pigment blend:

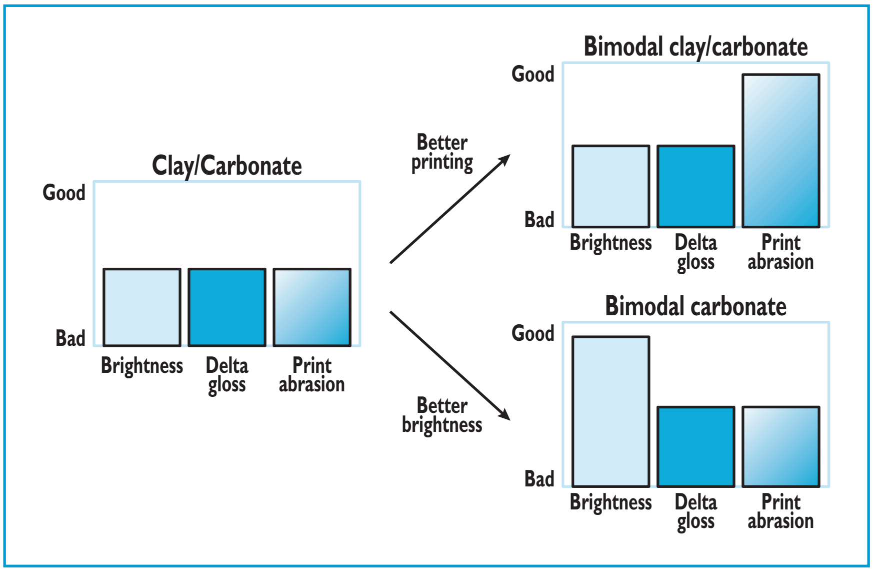
- Coarse GCC with an ultrafine GCC
- Coarse GCC with an ultrafine clay.

Note that care is necessary in production of coarse GCC to ensure minimum material > 10 µm since such very coarse particles would lead to excessive blade wear.

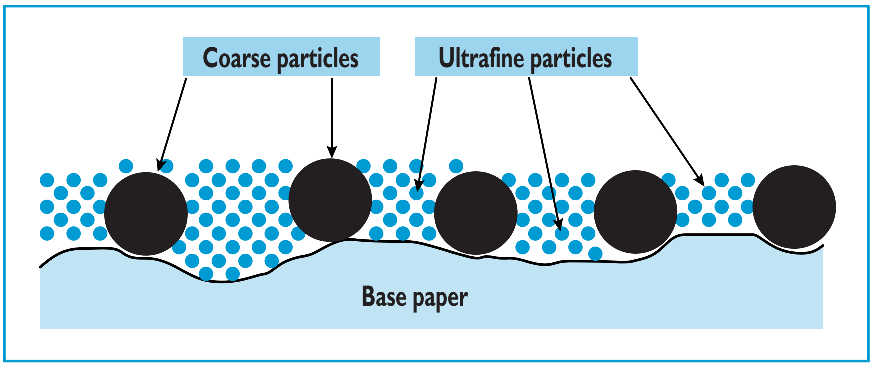
EFFECT OF DIFFERENT ULTRAFINE PIGMENTS

Top coating onto a precoated wood free base paper

This study used a coating station at our pilot coating center run at 900 m/min with a target coating weight of 12 g/m² per side on an 81 g/m² precoated wood free base sheet. Calendering of the coated papers used the hot soft nip calender at 900 m/min with one nip per side at 100°C using three pressures of 100, 200, and 300 kN/m to allow comparison of papers at given sheet gloss targets. The binder system had 5 pph medium viscosity starch and 8 pph styrene butadiene latex. An ultrafine



7. Development targets for matte coating pigments

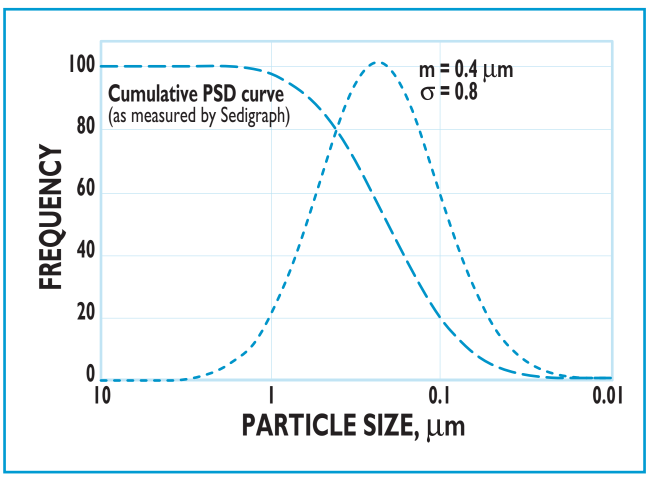


8. Coating structure generated by a blend of coarse and ultrafine particles

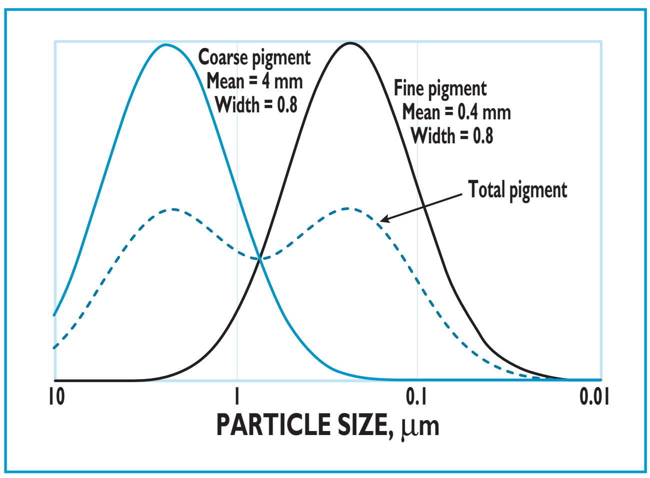
GCC (pigment F) and an ultrafine clay (pigment G) were blended with a coarse GCC (pigment A). **Table I** gives pigment details.

Calendered sheets were tested for optical properties, gloss, and smoothness using TAPPI test methods. Print gloss and print density used a commercially available tester, and print abrasion and wet pick measurements used a tester whose details are available from the authors. **Table II** gives sheet properties interpolated to a gloss value of 25.

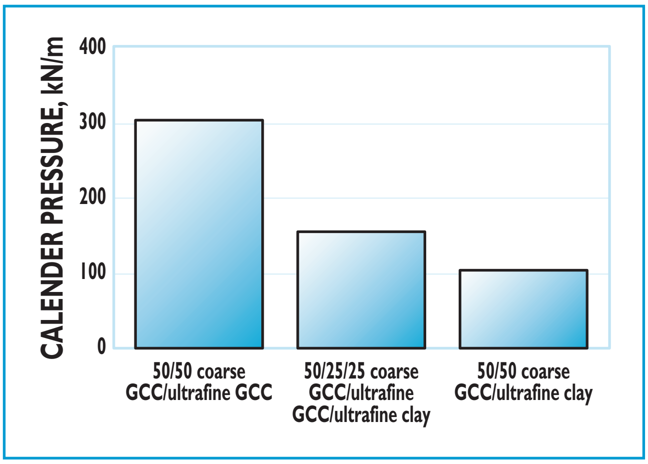
Table II and **Fig. 11** show that more pressure was necessary to calender the bimodal coatings containing the ultrafine GCC (pigment A+F) than those containing the ultrafine clay (A+G) to obtain a given sheet gloss. This indicated that coatings produced using the GCC bimodal pigment should be more resistant to marking during printing and binding or subsequent handling. As expected, the paper made using all GCC pigment blend has superior sheet brightness of about three units as **Fig. 12** shows but has about one unit lower opacity as **Fig. 13** shows. The use of progressively more ultrafine clay resulted in a reduction in print abrasion compared with the all GCC bimodal pigment blend as **Fig. 14**



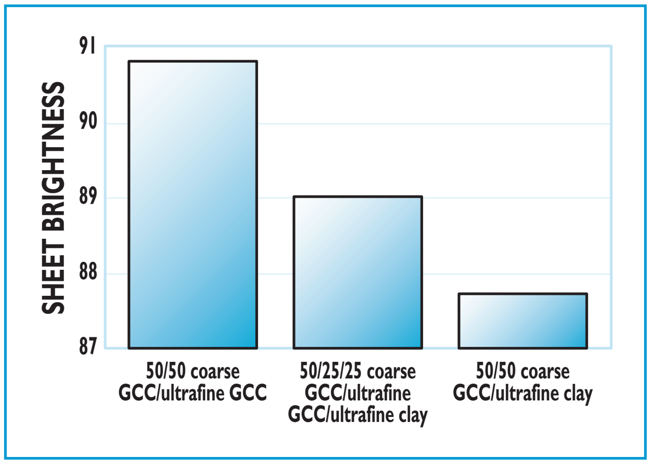
9. Log normal size distribution



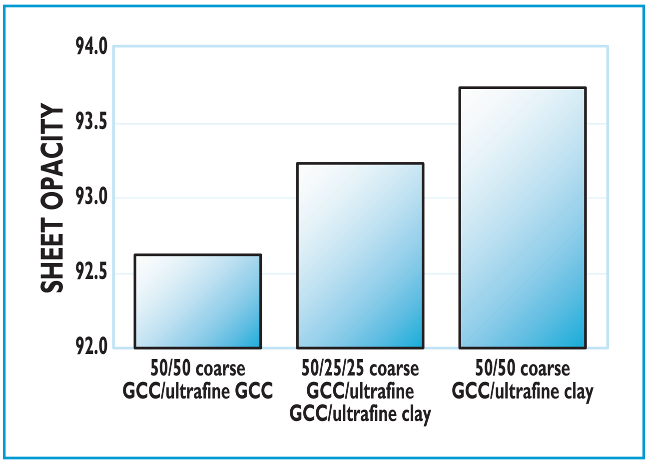
10. Particle size distribution for typical bimodal pigment

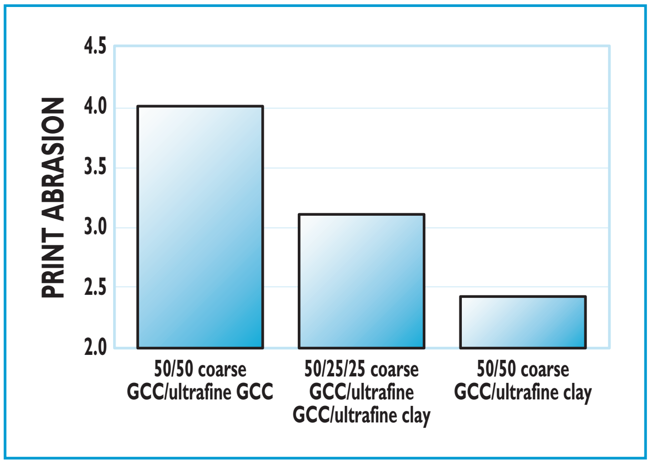


11. Gloss at different calender pressures



12. Sheet brightness at constant gloss





shows. The print gloss and density values showed little variation except the litho print tests of the all GCC blend where a small degree of water interference mottle produced low values. This coating was probably overly bound, and a reduction in binder level would remove this print defect. All the wet pick strength values showed that the coating had satisfactory strength.

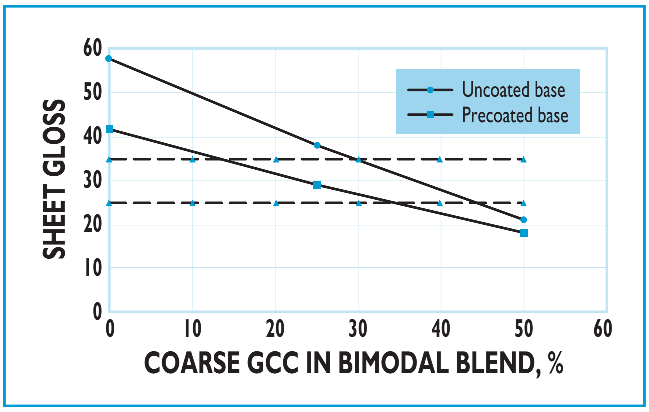
Single coating on a wood free base paper

Commercial matte grades may be single or double coated. The intent of this exercise was to establish whether the new pigment strategy could also apply in single coating. The base paper in this study was a 65 g/m^2 European uncoated wood free base paper. The coatings used a commercially available laboratory coater run at 400 m/min with a 45° blade angle. The colors used 12 pph of styrene butadiene latex, 4 pph of medium viscosity starch, 0.75 pph of stearate lubricant, and 0.1 pph of a crosslinking agent. The reference pigment was a blend of U.S. No. 1 clay (pigment H) with 60% < 2 µm GCC (pigment B). This was compared with a clay/GCC (pigment J/pigment A) bimodal blend and an all GCC (pigment F/pigment A) bimodal blend. The colors were coated at 64% solids by weight to achieve a target coating weight of 15 g/m^2. Coated sheets were calendered using a laboratory soft nip calender operated at 20 m/min and 55°C for one nip. Variation of the pressure gave gloss value of 30. **Table III** gives paper and print results.

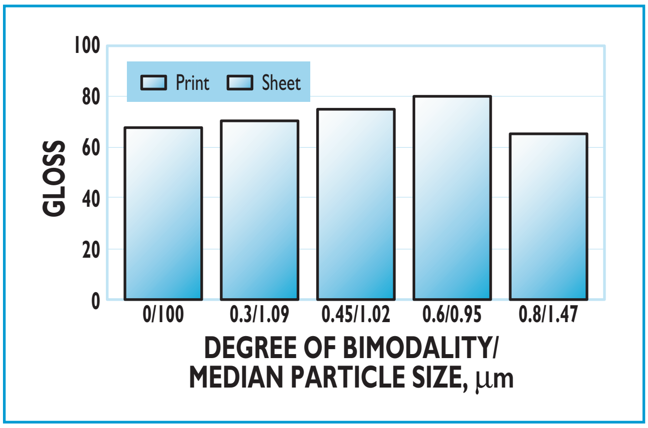
The results clearly show that moving from a standard to a bimodal clay/GCC blend improves print abrasion without affecting delta gloss but a slight change in surface brightness. Alternatively, changing to an all GCC bimodal blend maintains print abrasion and delta gloss while increasing brightness by a unit. Bimodal blends therefore give benefits in single and double coating.

OPTIMIZING PIGMENT FOR PARTICULAR BASE PAPERS

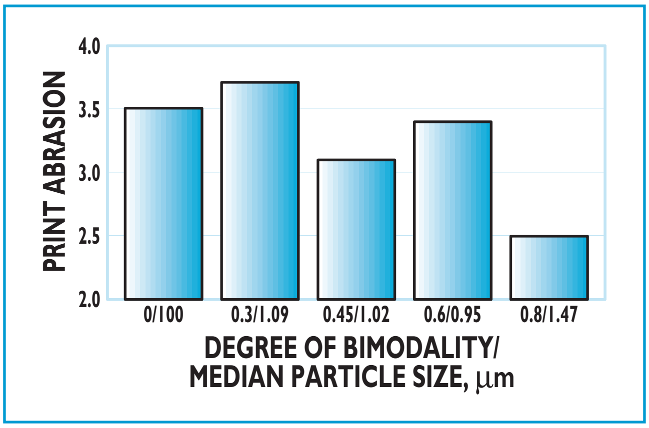
The type of base paper used will play a significant role in determining the ratio of coarse to ultrafine material necessary to achieve the required property balance. If the base is rough and porous, the ultrafine material will probably preferentially penetrate the base and a higher ultrafine



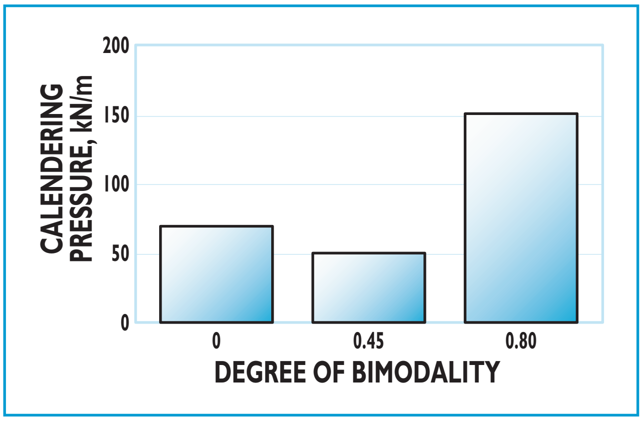
15. Effect of blend ratio on gloss



16. Influence of degree of bimodality on gloss



17. Influence of degree of bimodality on print abrasion



18. Calenderability of bimodal blends

pigment content will be necessary to maintain the correct ratio of coarse/fine material remaining in the topmost coating layer. If the base has been percolated and is smooth, then less ultrafine material may be necessary since none will be lost in the surface pores of the substrate. To assess the degree of this effect, the following study compared the performance of bimodal GCC blends in single and double coated applications. The uncoated base paper was a 105 g/m² European wood free base sheet. The precoated base was prepared by applying 10 g/m² of coarse GCC using a pilot coater.

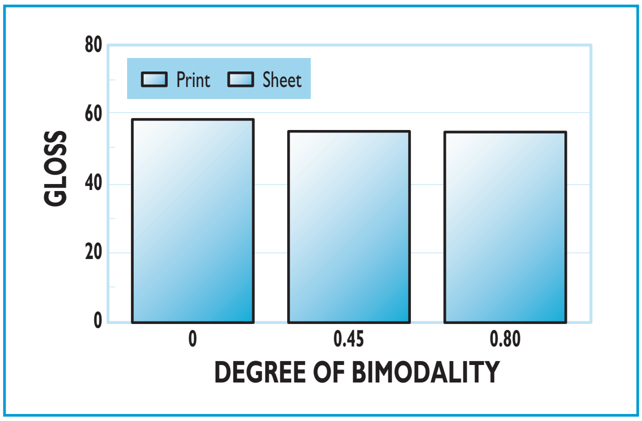
The bimodal coatings used a laboratory coater run at 400 m/min with a blade angle of 45°. Starch was the sole binder at 15 pph with 0.3 pph of crosslinking agent. The coated papers were supercalendered at 65°C at a pressure of 60 kg/cm for five nips at a speed of 36 m/min. **Tables IV and V** give paper and print test results at 10 g/m² coating weight, respectively.

With an uncoated base sheet, the results show that only about 25% of the coarse GCC is necessary in the bimodal blend to produce a semi-matte or satin grade, i.e., less than 30 gloss. About 40% is necessary when using the precoated base as **Fig. 15** shows. This confirms that more fine component is lost into the uncoated base than with the precoated base. The fine component therefore needs to be more of the blend with single coating. Differences in the ratio of coarse to ultrafine material will cause different binder demands that will require optimization for each application.

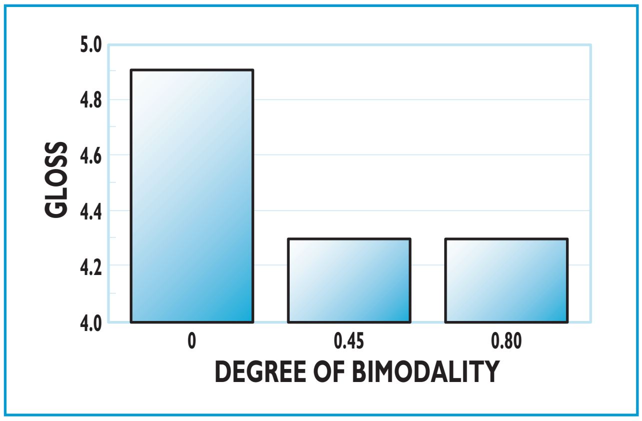
Note that Table V shows that the print abrasions for the double coated paper were higher than those measured for the single coated paper. This is probably due to the higher amounts of ink on the double coated paper surface because of greater hold out as evidenced by the higher print densities.

CHANGING DEGREE OF BIMODALITY—LABORATORY STUDY

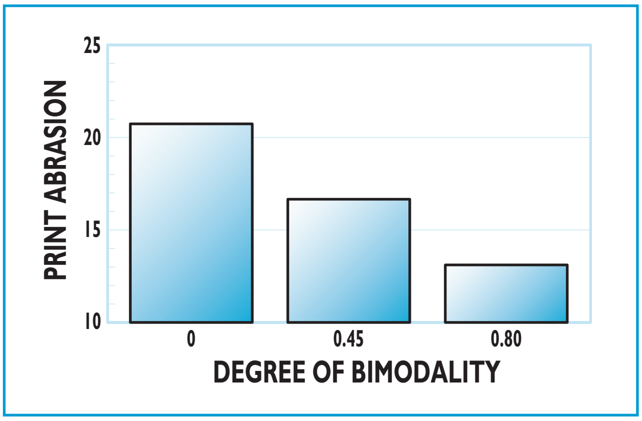
Another fundamental question of this type of system is how much bimodal character is necessary to obtain significant improvements in paper and print quality. A series of GCC pigments was used ranging



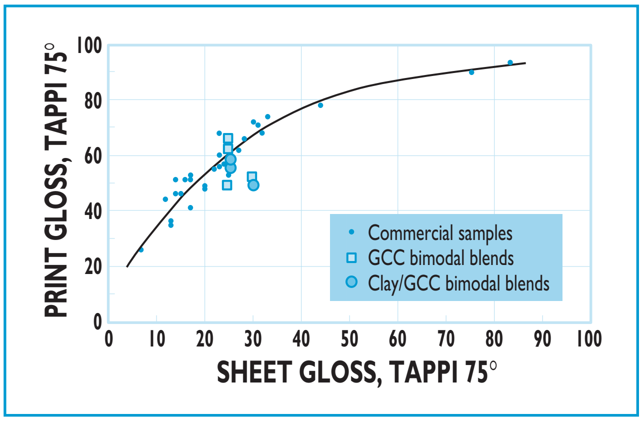
19. Influence of bimodality on gloss in pilot coater study



20.Influence of bimodality on print abrasion in pilot coater study



21. Influence of bimodality on print abrasion in commercial print trail



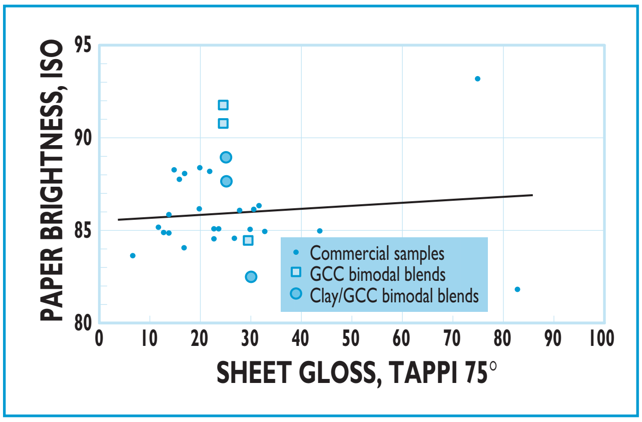
22. Comparison of bimodal pigments with commercial bench-marking for gloss

from coarse to ultrafine to test this question. Table I shows pigment details. The different pigment blends had about the same mean particle size with varying degrees of bimodality as **Table VI** shows. The formulation used consisted of 5 pph styrene butadiene latex, 10 pph low viscosity starch, 0.5 pph crosslinking agent, and NaOH to adjust the pH to approximately 8.5. The coatings were applied to the same precoated wood free base paper as noted above. The colors were applied at 400 m/min on the coater at a blade holder angle of 45° to provide a coating weight of 10–11 g/m^2 for each color. The papers were calendere using a laboratory supercalender at 65°C, 55 kg/cm pressure, five nips, and 36 m/min speed. **Tables VII and VIII** give paper and print properties, respectively.

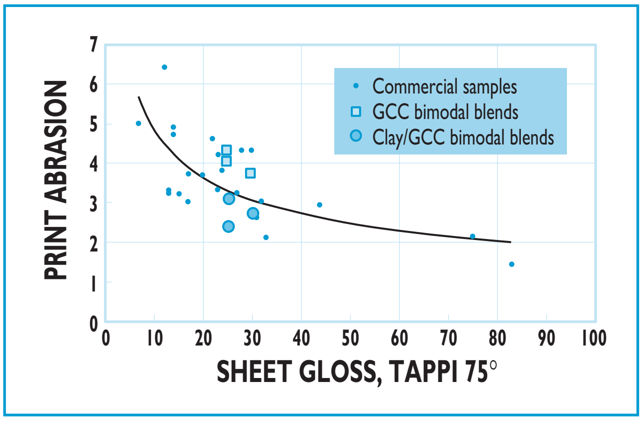
As expected, as the median particle size of the blends decreased in the order B+D > B+E > B+F, the sheet gloss increased. For the blends with bimodality ≤ 0.6, this did not affect the increase in gloss on printing (delta gloss) as **Fig. 16** shows. The other paper properties did not change with the change in pigment composition. No signs of print mottle were evident in the dry printed areas. Although the L/D print density ratios were all greater than that required for a satisfactory commercial print (0.80), the reduction in print density with all the samples was significant. This and the high wet pick test results (all >270 cm/s) indicate that the coatings were overly bound. The print abrasion results in **Fig. 17** show the superior performance of the GCC blend with the highest degree of bimodality (A+F).

CHANGING DEGREE OF BIMODALITY—PILOT COATER STUDY

Our study included a similar coating run of various bimodal pigments using a pilot coater. Considering the previous results, this evaluation used lower binder levels, i.e., 8 pph latex with 0.5 pph low viscosity carboxymethyl cellulose (CMC). Both sides of an 81 g/m^2 precoated wood free base sheet were coated with 10 g/m^2 coating weight at 900 m/min. The resulting papers were hot soft nip calendered at 900 m/min, 100°C, one nip/side, and three pressures of 50, 150, and 250 kN/m. A range of calendering pressures was used to try to determine the susceptibility to calendering of the various bimodal pigment blends. **Table IX** gives interpolated results at 25 sheet gloss.



23. Comparison of bimodal pigments with commercial benchmarking for brightness



24. Comparison of bimodal pigments with commercial benchmarking for print abrasion

As the bimodality increases, the calendering pressure required to reach the target sheet gloss level significantly increases as **Fig. 18** shows. This indicates a less compressible coating layer that is less susceptible to marking. Print gloss and therefore delta gloss were lower when a high degree of bimodality was present as **Fig. 19** shows. **Figure 20** confirms that bimodal pigments give reduced print abrasion compared with the 75% < 2 µm GCC sole pigment formulation. No general relationship exists between print abrasion and print gloss.

The same pilot coated papers were commercially printed to ensure that the differences seen in the laboratory printing results were significant. **Table X** presents the results. Samples of the printed sheets are available on request. Seeing differences in the printed sheets were very difficult with visual inspection. The print gloss advantage of pigment C in the commercial prints was greater than that seen in the laboratory tests. This was probably due to the different inks since past work indicated inks can exhibit varying degrees of print abrasion and gloss. Sacrificing some calender resistance to increase the print gloss of the bimodal GCC blends would be possible by increasing the ultrafine pigment in the blend. Although the print abrasion results were much higher than those of the laboratory printing work, the same trend was evident as **Fig. 21** indicates. This means that obtaining a very low laboratory measured print abrasion result is important.

COMPARISON WITH COMMERCIAL PAPERS

Our two possible development targets were to achieve a matte paper with the same print performance as present but with improved sheet brightness or improved print abrasion. **Figure 22** shows that most bimodal blends tested do fall within the print gloss range of commercial paper samples. **Figure 23** shows that bimodal pigments can give a step change in sheet brightness levels, and **Fig. 24** indicates that use of an ultrafine clay/GCC bimodal pigment can give significant improvements in print abrasion.

CONCLUSIONS

The new pigment design gives significantly different paper and print properties for producing matte coated papers. The use of bimodal pigments allows formation of a rigid coating layer resisting calendering and marking.

A bimodal pigment blend of coarse and ultrafine GCC can produce print abrasion values similar to those of commercial papers but with a significantly higher sheet brightness. The bimodality of an all GCC system does influence the printing properties of the coated paper. As bimodality increases, the print abrasion decreases, but the print gloss suffers slightly. Changing the ratio of coarse to ultrafine material would rectify this.

Significantly improved print abrasion properties are possible by using a bimodal blend of coarse GCC and an ultrafine clay. The bimodal pigment system requires optimization of the pigment blend and binder system to the target coating system. A single coated paper will require a different pigment and binder package compared with a double coated paper. **TJ**

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Particle size, µm	GCC A	GCC B	GCC C	GCC D	GCC E	GCC F	Ultrafine clay G	No. 1 clay H	Fine No. 1 clay J
0.5	10	22	30	39	47	56	92	64	80
1	21	38	50	65	78	90	96	81	92
2	40	60	75	90	95	98	98	91	96
5	81	90	96	98	99	100	100	100	100
10	99	99	99	100	100	100	100	100	100

I. Particle size distributions of pigments showing cumulative mass percentage finer than the given particle size

Pigment blend			Calender pressure, kN/m	PPS @ 10 kgf, µm	Sheet brightness	Sheet opacity	Print gloss,		Print density,		Print abrasion	Wet pick cm/s
A	F	G					dry	litho	dry	litho		
50	50		300	1.5	90.8	92.6	61	49	1.44	1.01	4.0	120
50	25	25	150	1.8	89.0	93.2	60	56	1.45	1.37	3.1	130
50		50	100	1.6	87.7	93.7	63	59	1.49	1.32	2.4	110

II. Top coating on precoated wood free paper with interpolated values at sheet gloss = 25

Pigment 50/50 blends	Pigment type	Calender pressure, kN/m	Brightness, ISO	Opacity	Print gloss, dry/litho	Delta gloss, dry/litho	Print abrasion
Clay H/GCC B	Standard	50	83.3	87.0	59/53	30/24	3.5
Clay J/GCC A	Bimodal	50	82.6	86.6	57/50	29/22	2.7
GCC F/GCC A	Bimodal	300	84.4	85.6	60/52	32/24	3.7

III. Single coated wood free paper with interpolated values at sheet gloss = 30

Pigment blend	Uncoated base				Precoated base			
	Gloss	Brightness, ISO	Opacity	PPS, 10 kg	Gloss	Brightness, ISO	Opacity	PPS, 10 kg
GCC F	43	92.0	92.4	1.22	58	90.9	93.2	0.81
25/75 GCC A/ GCC F	29	92.1	92.2	1.46	38	91.1	93.0	1.03
50/50 GCC A/ GCC F	18	92.1	92.2	1.67	21	91.2	92.9	1.28

IV. Effect of base paper type showing print properties at 10 g/m² coating weight

Pigment Blend	Uncoated base				Precoated base			
	Print gloss	Delta gloss	Print density	Print abrasion	Print gloss	Delta gloss	Print density	Print abrasion
GCC F	64	21	1.27	4.0	84	26	1.43	5.0
25/75 GCC A/ GCC F	49	20	1.20	4.1	71	33	1.39	4.8
50/50 GCC A/ GCC F	36	18	1.12	4.5	47	26	1.23	5.4

V. Effect of base paper type showing print properties at 10g/m² coating weight

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	Pigments							
	A	B	C	D	E	F	Degree of bimodality	Median particle size, µm
1			100				0	1.00
2		50		50			0.3	1.09
3		50			50		0.45	1.02
4		50				50	0.6	0.95
5	50					50	0.8	1.47

VI. Pigment blends for study on effect of degree of bimodality

Blend	Coating Weight	Uncalendered results Gloss	Brightness	Opacity	PPS10	Calendered results Gloss	Brightness	Opacity	PPS10
1	10.7	10	90.6	94.0	3.17	28	90.1	93.3	1.09
2	10.3	10	90.8	93.8	3.38	28	90.3	93.2	1.10
3	10.5	13	90.4	94.2	3.36	32	89.9	93.4	1.07
4	10.1	15	90.6	94.1	3.24	37	90.1	93.3	1.03
5	10.3	8	90.4	94.0	3.97	25	89.8	93.4	1.13

VII. Effect of degree of bimodality on paper properties

Blend	Coating weight	Paper gloss	Print gloss, dry/litho	Delta gloss, dry/litho	Print density, dry	Print density, litho	L/D	Print abrasion
1	10.7	28	67 / 62	39 / 34	1.43	1.29	0.90	3.5
2	10.3	28	70 / 62	42 / 34	1.43	1.25	0.87	3.7
3	10.5	32	74 / 67	42 / 35	1.48	1.34	0.91	3.1
4	10.1	37	79 / 69	42 / 32	1.50	1.24	0.83	3.4
5	10.3	25	64 / 53	39 / 28	1.42	1.18	0.83	2.5

VIII. Effect of degree of bimodality on print properties

Pigment	Calender pressure, kN/m	Brightness	Opacity	Print gloss, dry/litho	Delta gloss, dry/litho	Print abrasion
50/50 A/F + 8 latex	150	91.8	92.2	65 / 61	30 / 26	4.3
50/50 B/E + 8 latex	50	91.8	92.6	65 / 62	30 / 26	4.3
100 C + 8 latex	70	91.8	92.6	68 / 66	33 / 31	4.9

IX. Effect of bimodality in pilot coater study with interpolated results for 25 sheet gloss

Pigments	Print gloss, Y/B/M/C	Print density, Y/B/M/C	Print abrasion	Wet pick
50/50 A/F	51/59/51/52	0.86/1.60/1.25/1.33	13.0	>270
50/50 B/E	55/64/53/54	0.89/1.66/1.21/1.30	16.6	>270
100 C	60/70/60/59	0.89/1.67/1.27/1.30	20.7	>270

X. Commercial print trial results at 25 sheet gloss and 10 g/m² coating weight