Effects of sheet moisture and calender pressure on PCC and GCC coated papers

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ABSTRACT: Previous work demonstrated that narrow distribution coating PCC allows high moisture calendering with no loss of optical properties of coated papers. Broad particle size distribution pigments exhibit a significant loss of optical properties, when moisture increases and supercalendering pressure is adjusted to achieve a gloss target. In this study, we rationalize these results by considering macro- and micro-smoothness and demonstrating that narrow distribution coating PCC produces high micro-smoothness even in the absence of supercalendering. Calendering is necessary only to supply macro-smoothness through base paper deformation. Therefore, at high moisture, pressure can be reduced so that no additional base paper deformation occurs and optical and physical properties of the final coated paper are equivalent to those achieved with lower moisture and higher pressure.

Application: One concept for achieving increased productivity is through a coating that would require less drying, via pigment selection. Manufacturers can translate this concept into either increased coater speed or reduced drying energy.

Well-documented experimentation has demonstrated the relationship between the paper substrate, the coating, and the final smoothness and gloss of a coated paper. Early work by Oittinen [1] attributed the macroscopic smoothness, or macro-smoothness, of a coated paper to the fiber base. The micro-smoothness was directly attributed to the coating pigments. According to Oittinen, good macro- and micro-smoothness are required to achieve higher gloss.

Variables such as calendering intensity, temperature, and moisture have been thoroughly studied, and with most pigment systems, the trends and expectations are well established. Many of these experiments are focused on temperature or temperature gradients alone. Information from these studies supports the theory that the substrate, or base paper, defines macro-smoothness. Whether using a temperature gradient or a single elevated temperature, the effect of increased temperature is similar: the base becomes more deformable, conforming to the coated layer, thus improving both macro- and micro- smoothness.

Regardless of the pigment system used, the basic principle is to calender the paper to improve the quality of both the base paper and coated layers. Calendering changes both the paper surface and paper sheet interior, but the degree of change in each layer depends on the variables mentioned above. While it is accepted that the base paper determines macro-smoothness, the pigment contribution dominates the micro-smoothness. To improve gloss, both the macro- and micro-smoothness must be achieved.

The importance of manipulating the base paper layer during calendering is emphasized by Vreeland [2, 3]. Vreeland explains that the paper base is deformed by heating the substrate above the glass transition temperature (Tg) of cellulose, while providing enough pressure and dwell time to allow the substrate to conform to the coating. The result is increased macro-smoothness and gloss. Linnonmaa, et al., [4] discuss using a temperature gradient and increased moisture during calendering, which preserves the coating structure. This study shows that a precipitated calcium carbonate (PCC) coating pigment system responds very quickly to increases in temperature and moisture, enabling the PCC coating to reach the desired micro-smoothness and gloss at lower calendering pressures.

The optics and other coated paper properties may be preserved by taking advantage of the gloss gain that high moisture brings. The line load can be dramatically reduced, while keeping calendering temperature constant through increasing the sheet moisture content [5]. This was shown with PCC, but not with coatings containing high amounts of ground calcium carbonate (GCC) or ultra-fine clay-containing coatings. One factor limiting increased moisture content is the residual effect of the higher moisture during web offset printing. Small increases in coated paper moisture can cause blistering during printing. Through the use of a more open coating structure, such as with PCC, moisture levels can be increased and gloss maintained while avoiding blister. The blister resistance of PCC is well documented [5, 6] and is something other small particle size pigments, such as ultra-fine clay and ultra fine GCC, have not demonstrated. (See **Appendix B** regarding data from the relevant study.)

In addition to the effects of moisture and temperature, different calendering loads have also been studied. Mercury porosimetry shows that the coating pore volume decreases with calendering intensity. When using pigments that may need more pressure to reach a set level of paper gloss, or micro-smoothness, a decrease in overall porosity is expected, in both the coating and base paper layers. Most reports on this subject focus

Coating #	1	2
PCC pigment	70	
GCC pigment		70
Ultra-fine clay pigment	30	30
Carboxylated SB latex	14	14
Calcium stearate lubricant	1	1
CMC thickener	0.8	0.8
Optical brightener	0.5	0.5
Dispersant	0.1	0.1
Application solids, %	64.5	64.6
pH	8.69	8.56
Brookfield viscosity, mPas @ 100 rpm	1394	1714
Hercules® Hi-Shear viscosity, mPas @ 4400 rpm	32.5	42.1
Water retention ÅA-GWR, g/m²	218	206
Temperature, °C	30.8	31.6

I: Coating formulations

	PCC	GCC	Ultra-fine Clay
Average Particle Size, µm	0.42	0.68	0.21
Surface Area, m²/g	11.7	12.4	22.3

II: Pigment characteristics

Basis Weight, gsm	63
TAPPI brightness, %	84.8
TAPPI opacity, %	84.5
Hunter L	91.79
*a	1.02
*b	-2.38
PPS-10 roughness, mL	5.03
Gurley porosity, sec. @ 10cc	15

III: Base paper characteristics

on the final coated paper optics, strength, printability, and to some extent the mercury porosimetry showing the coating structure changes.

In this paper we show that not only can the pore structure of the PCC coatings be maintained with moisture and pressure changes, but by taking advantage of both the inherent micro-smoothness of the small, aragonitic PCC, the pore structure of the substrate can also be maintained.

EXPERIMENTAL

We performed the entire coating makedown, coating application and calendering process on pilot scale at the Centre International de Couchage in Trois-Rivières, Quebec, Canada. We examined two different pigment systems for #2 coated woodfree grade web applications: a small particle size, narrow-distribution aragonitic PCC and a medium, broader-distribution ground calcium carbonate (GCC), both with ultra-fine clay. These formulations were selected from a wider range of coating colors that were used in a previous study, as they best illustrated the principles discussed herein. **Table I** lists coating formulation and coating color characteristics. Characteristics of the pigments used for each coating are in **Table II**.

We adjusted each coating color to a pH of 8.5-9.0 as necessary. The application solids of the coatings were near 64.5% for both coatings. Each coating was applied at the target solids, achieving coated sheets without defects such as streaking, spitting, or scratching.

The base paper used for this study was an uncoated, non-sized paper woodfree paper. General characteristics of the base paper are listed in **Table III**.

The target coat weight was 14 g/m² per side, applied with a 0.457 jet/blade with 45° bevel. For each coating formulation, the web was dried to three different moisture levels, targeting final sheet moistures of 5%, 6%, and 7% at the reel. The different moisture levels were reached through decreased drying in the flotation dryer sections as required.

We performed calendering with an 11-nip supercalender at 400 m/min. Each coating at each moisture level was calendered at a set line load of 396 kN/m. Calendering load was also varied for each point to reach a target gloss. We determined the target gloss from the gloss achieved with the PCC formulation at 5% reel moisture. The temperature used for zones 1-3 remained at 90°C through all of the conditions.

Printing was performed at the Rochester Institute of Technology (RIT), in Rochester, NY, USA. The samples were printed by heat-set web offset (HSWO) on a Heidelberg Sunday® 2000 press. Blister resistance was successful for each of the trial points evaluated. No blistering was observed within the print surfaces, including those having a solid ink layer, for any of the trial points examined.

We performed paper testing in constant temperature and humidity conditions according to TAPPI Standards. Each property was tested by measuring 6 test points on 6 coated sheets (36 total measurements). The properties we tested in this manner include gloss, opacity, brightness, roughness, porosity, caliper, print gloss, and basis weight. Sheet bulk

Pigment Slip	70/30 PCC/ Ultra-fine Clay			70/30 GCC/ Ultra-fine Clay		
Target Moisture After Coating	5	6	7	5	6	7
% Moisture, After Coater	5	5.8	6.6	4.9	6.0	6.8
% Moisture After Calendering	3.2	3.4	3.7	3.2	3.4	3.8

IV: Online-scanner moisture of the coated paper after coater & after calendering

Coating #	1	2
Pigment	PCC	GCC
1st Moisture Level, %	5.0	4.9
T_g at 1st Moisture, °C	121.6	123.2
2nd Moisture Level, %	5.8	6.0
T_g at 2nd Moisture, °C	109.5	106.7
3rd Moisture Level, %	6.6	6.8
T_g at 3rd Moisture, °C	98.6	96.1

V: Calculated cellulose T_g for moistures used for each coating

was calculated from values obtained from caliper and basis weight testing (bulk = caliper / basis weight *25.4). The print gloss and optical density testing was performed on printed samples from HSWO printing performed at RIT.

The target moistures at the reel after coating were 5%, 6%, and 7%. We adjusted the moisture to reach target levels as measured by an on-line scanner at the winder after coating. The reel moistures decreased significantly after calendering, changing the post coater moisture by approximately 2% to 3%. The final sheet moistures after calendering ranged from about 3% to 4%. The target moisture level, on-line scanner moisture at the winder after coating, and on-line scanner moisture after calendering were recorded for each trial point, and are shown in **Table IV**. Results will be discussed using the pre-calendering moisture values as measured by the on-line scanner.

Aside from steps taken to wrap the reels in plastic directly after calendering until printing, we made no further efforts to control the moisture, and made all comparisons based on the on-line scanner data.

We performed this study initially to determine how much of an advantage the open coating structure of a PCC coating has relative to the blistering in heat-set web offset printing for #2 coated woodfree grades. Our initial study included several different calcium carbonate variations at different ratios to reflect some of the current systems used in different regions. We expected improved blister resistance with PCC. One outcome we did not anticipate was a distinct shade difference between PCC and GCC coated papers at equal moisture content after calendering to an equal gloss target.

The appearance of coated, calendered paper suggested that fiber crushing/calender blackening had occurred as moisture levels were increased, but to different extents between the PCC and GCC coatings. Since this would be largely independent of coating compaction, we examined the different coated papers and the substrate porosity, using mercury porosimetry to determine how the fiber structure of the paper below the coating was affected with increasing moisture. This report details the findings from that examination, and focuses on the two coatings that give such vastly different results: the PCC and GCC coatings, so that the effects of each may be clearly illustrated.

RESULTS

Quality coated gloss is dependent on two factors: micro-smoothness and macro-smoothness. Macro-smoothness is determined by the base paper. Deformation of the base can be achieved through a combination of variables such as pressure, temperature, and moisture. As Vreeland showed, by using a high enough temperature and moisture content, the T_g of the fiber could be used to mold the fiber to the coating. Vreeland [2] describes this equation, where:

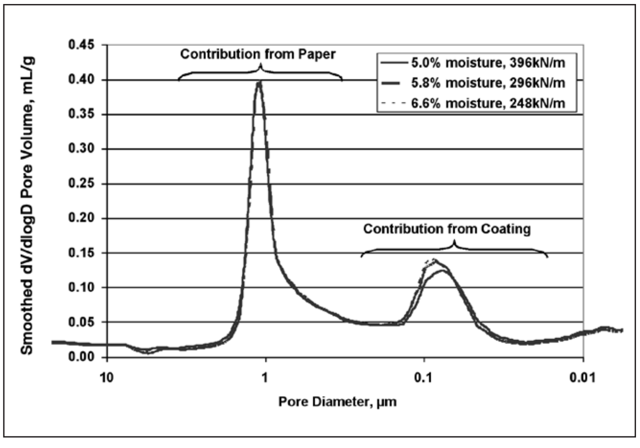
$$T_g = 234.2e^{-0.131m}$$

T_g = the glass transition temperature under the dynamic and moisture conditions existing in the nip, °C
e = the base of the natural logarithm
m = moisture content of the fibers in the web in % of the bone dry weight of the fibers

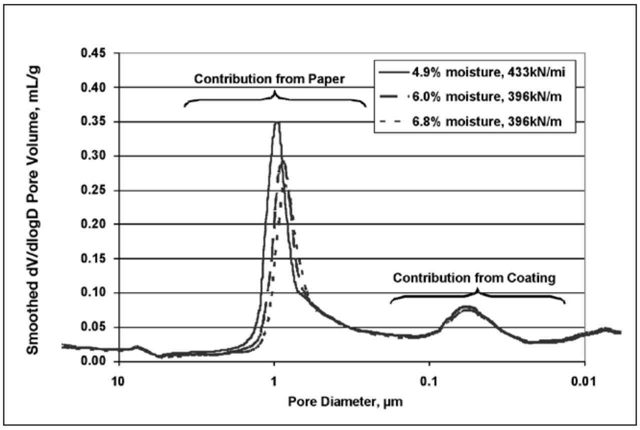
Using this equation and the moisture levels examined in this study, we calculated the T_g for each condition to reach cellulose T_g and mold to the coated surface (**Table V**).

Vreeland's equation for T_g predicts that there should be no deformation or loss of pore structure of the base sheet through thermal means. The calendering temperature used in this study was 90°C. Only at the highest moisture level used, targeting 7% off the reel of the coater, did the calculated cellulose T_g approach the temperature used during calendering. Both the PCC and GCC coating formulations had a cellulose T_g 5-10°C over the calender temperature used. Thus, the paper did not reach the predicted threshold necessary to reach thermal deformation.

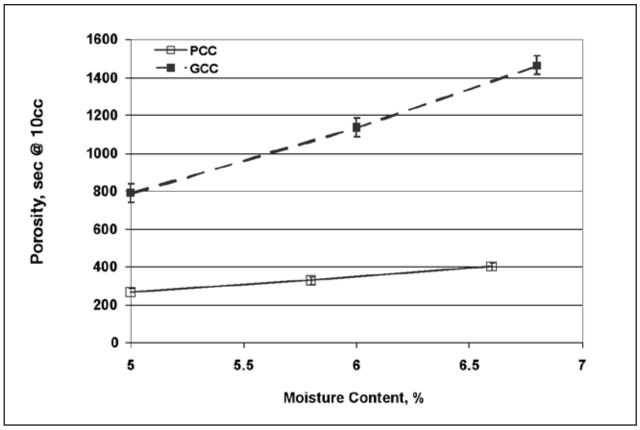
Following the prediction that the deformation of the base will not occur through thermal means, the mercury intrusion shows that, as moisture is increased and pressure ***decreased*** to reach the equivalent gloss of the low moisture control, the pore volume of both the base and the coating can be maintained with the PCC coatings from 5%-7% moisture. The GCC coatings did deform as moisture increased above 5%, starting



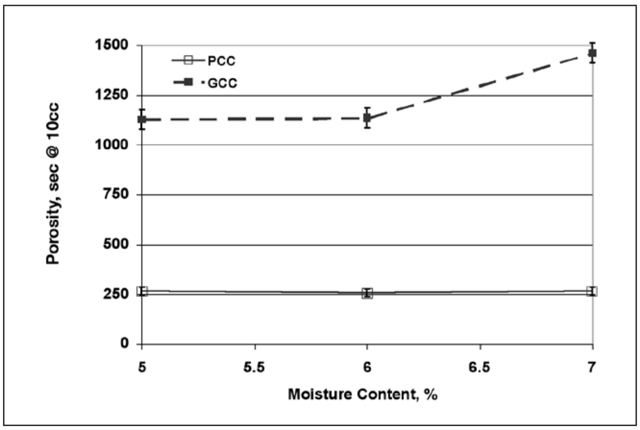
1. Mercury porosimetry: PCC coating calendered to 84 sheet gloss as moisture increases



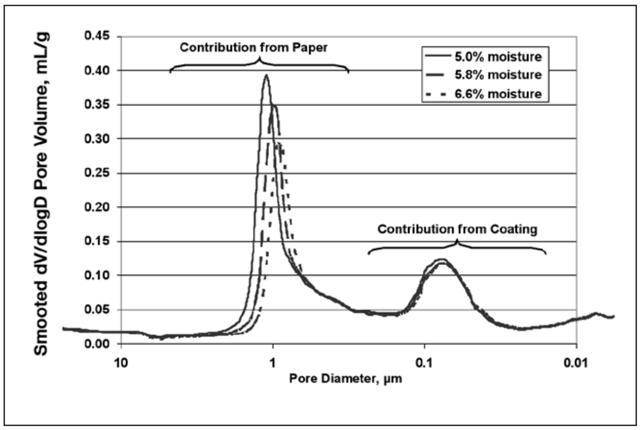
2. Mercury porosimetry: GCC coating calendered to 84 sheet gloss as moisture increases



4. Sheet porosity as a function of moisture when calendering at constant line load



3. Sheet porosity as a function of moisture when calendering to equal gloss



5. Mercury porosimetry: PCC coating at constant line loading with increasing moisture

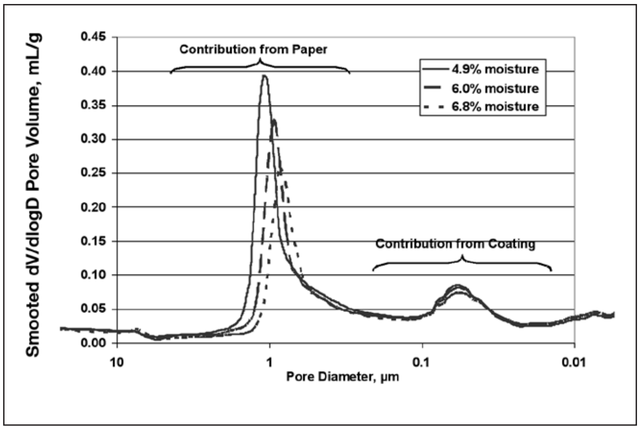
at 6% and deforming even more at 7%. See **Figs. 1** and **2**.

The coated sheet porosity as measured with the Hagerty device also demonstrated that the total coated sheet porosity is maintained as moisture changes (**Fig. 3**). If calendering is performed using a target line load, the total sheet porosity does change with increased moisture, as shown in **Fig. 4**. The coated sheet porosity with the GCC coating is much more affected by increased moisture, compared to the PCC coating. The overall change in coated sheet porosity from the low to high moisture level was 650 sec for GCC and 150 sec for PCC. **Tables VI** and **VII**, available in **Appendix C**, show the gloss and porosity averages and standard deviations of each of the trial points used in Figs. 3 and 4. For additional details on testing methods, refer to the Experimental section.

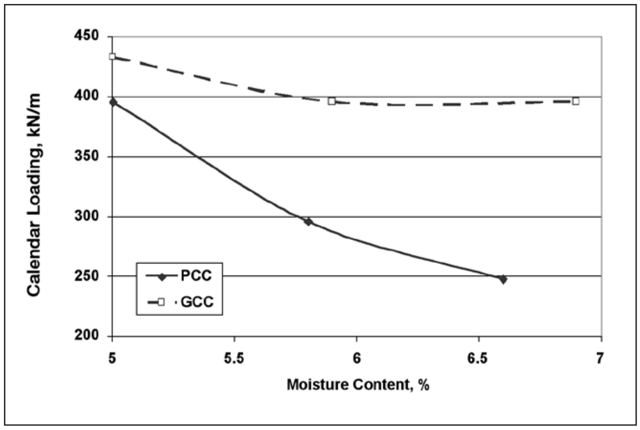
Although the thermal deformation calculations do not predict a loss of pore volume, some deformation of the base does occur if calendering conditions are changed. **Figures 5** and **6** show the decrease in pore volume of both the coating and the paper regions as the coated paper moisture increased when calendering to an equivalent line load (396 kN/m). This decrease in pore volume was very similar for both the PCC and GCC coatings as moisture increased. The GCC coating decreased from 0.39 to 0.26 mL/g in pore volume, and PCC coating decreased from 0.39 to 0.29 mL/g over the same moisture range.

The change in gloss, then, is attributed to a combination of pressure and moisture alone. Both the PCC and GCC coatings were calendered at equal line load and to equal gloss. As shown in **Fig. 7**, the coated paper gloss of the PCC coating was higher than that of the GCC at equal line load as moisture increased. This indicates that lower line loads could be used to reach target gloss compared to the GCC coating, which is illustrated in **Fig. 8**.

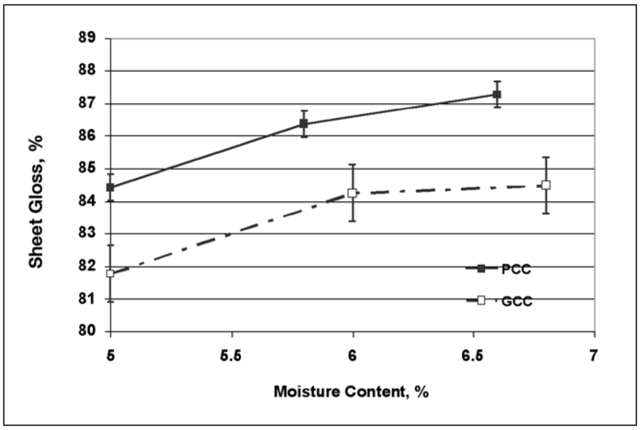
The conclusion is that the PCC generates gloss more quickly, and that extra deformation from the base is not necessary. GCC requires comparatively higher pressures to reach a target gloss because more pressure must be used to attain good micro-smoothness in the coating layer, indicating that base deformation is necessary to reach good micro-smoothness and gloss with GCC. This concept is demonstrated through bulk and porosity. At equal calender loading, both bulk and porosity decreased with increasing moisture (**Fig. 9**). When calender loading is adjusted to attain equal gloss, the sheet porosity and bulk are maintained with the PCC coating, but



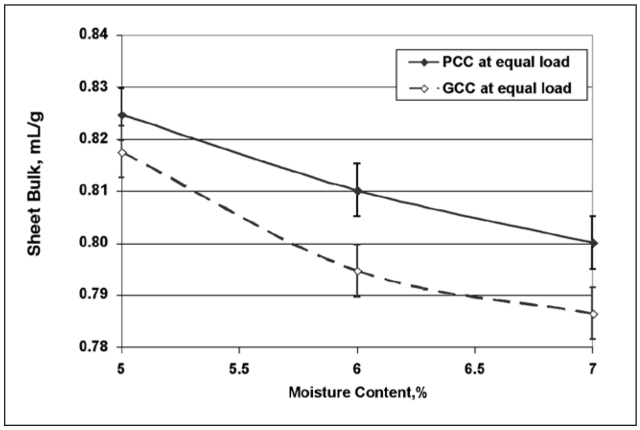
6. Mercury porosimetry: GCC coating at constant line load with increasing moisture



8. Calendering pressure as a function of moisture content at equal gloss



7. Gloss as a function of moisture at constant line loading



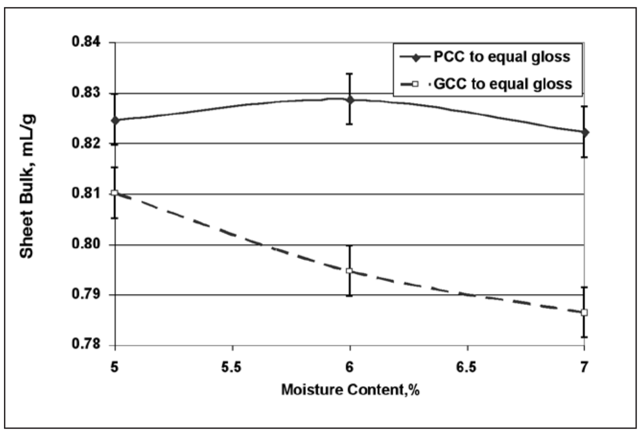
9. Sheet bulk as a function of moisture content at constant line load

not with the GCC coating (**Fig. 10**). **Tables VIII** and **IX**, available in Appendix C, show the sheet bulk averages and standard deviations for each of the trial points used in Figs. 9 and 10. For additional details on testing methods, see the Experimental section.

Micro-smoothness is derived from coating pigments [1]. Three conditions need to be met to attain good micro-smoothness from the pigments: (a) an alignment of pigment particles, (b) there should be no large particles present, and (c) shrinkage during immobilization should be minimized.

It is reasonable to assume that the aragonite PCC particles align in the shear field of the blade nip. By the very nature of the precipitation process, fine PCC, which comprises narrow particle size distribution, has few coarse particles. Additionally, with their relatively high aspect ratio, particle alignment is maintained upon consolidation. Also, due to the inherent pore structure that narrow particle size distribution pigments provide, the structure is maintained during consolidation.

GCC coatings have a random arrangement of particles at application, with both very large and very small particles present. After immobilization, a random particle arrangement still exists, and particle alignment is not possible. Due to the presence of large pigment particles, coating consolidation during



10. Sheet bulk as a function of moisture content at equal gloss

immobilization yields a compacted structure. The concepts are illustrated in **Figs. 12** and **13**.

Aragonite PCC pigments achieve improved micro-smoothness through particle alignment, absence of large particles and preservation of the particle structure during immobilization. GCC pigments cannot achieve particle alignment because they have an aspect ratio very close to 1 and have large particles present due to the broader distribution and consolidation of particles during immobilization.

To improve the smoothness of GCC comparable to PCC, more calendering is required. This means that base paper deformation is required through higher calender pressures which results, among other effects, in bulk reduction. As shown in Fig. 7, PCC had higher gloss with increased moisture at equal line load, and in Fig. 8, required lower line loads to reach the same gloss target compared to GCC. Because of the inherent micro-smoothness with PCC, coated paper smoothness and gloss are easier attainable without excess calendering of the base paper.

CONCLUSIONS

The pore volume of both the coating and paper substrate can be preserved during calendering through the use of increased moisture in conjunction with PCC. Negatives such as fiber crushing, blister, stiffness and loss of density can be avoided with aragonite PCC due to the ability of the PCC to maintain the coating structure during immobilization combined with the improved micro-smoothness resulting in less need for calendering, compared to other pigments such as GCC and ultra-fine clay.

ACKNOWLEDGEMENTS

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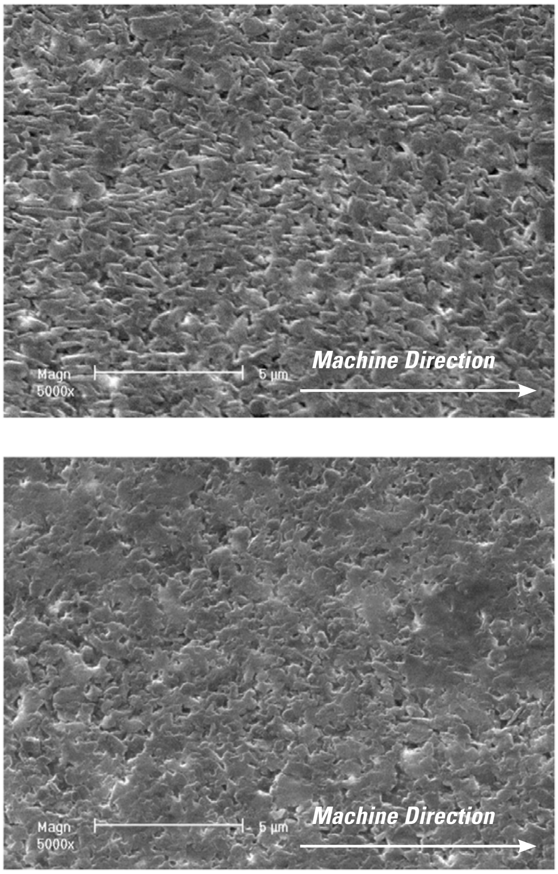
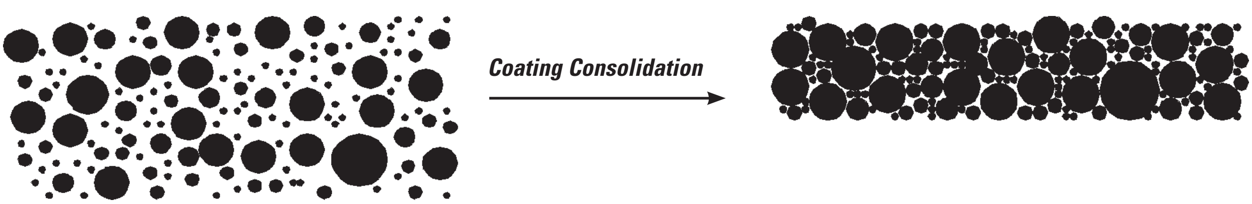
Coated Paper with PCC at 5000 magnification



11. SEMs of PCC and GCC coated paper surface

12. Conceptual representation of PCC particles before and after immobilization



13. GCC particles represented before and after immobilization

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APPENDIX A

Materials used for the coating formulations included the following: OPACARB® A40 PCC (registered trademark of Specialty Minerals Inc.'s affiliate in the U.S. and other countries), Hydrocarb® 90 GCC, Hydragloss® 90 Ultra-fine Clay, Dow XU 31294.5 latex, FinnFix® 10 Carboxyl Methyl Cellulose, Devflo™ 50 calcium stearate lubricant, Blancophor™ P optical brightener and Dispex® N-40 dispersant. Other named trademarks are owned by their respective owners.

APPENDIX B

Appendix B contains data and figures from Dimmick, A. and Huhtala, K., "Quality Performance Using Increased Moisture Content at the Reel with Woodfree Coatings," 2005 TAPPI Coating & Graphics Arts Conference Proceedings. (This complete paper is available free to TAPPI members through the TAPPI e-Library.)

We performed and demonstrated full optical and physical testing, printing, and print register as well as blister analysis within this referenced work to support statements made in the current work. Please refer to that paper for additional details. (Due to print space considerations, *TJ* subscribers may access Appendix B data and figures through the electronic version of this month's issue, and at www.tappi.org.)

APPENDIX C

Appendix C includes Tables VI-IX, which show averages and standard deviations for each of the trial points used in Figs. 3, 4, 9, and 10. (Due to print space considerations, *TJ* subscribers may access Appendix C through the electronic version of this month's issue, and at www.tappi.org.)

INSIGHTS FROM THE AUTHOR

There are many avenues to improving productivity. We chose to study the concept of coating design to improve coated paper productivity through the potential of decreased drying while maintaining coated paper properties. The increased productivity could be achieved through either reducing drying energy or faster machine speeds.

The ability of a coating to withstand increased moisture without suffering negative impacts of coated paper properties was previously demonstrated. This work showed that, through the use of a narrow distribution coating PCC, coated paper could be dried less and calendering reduced without a loss of optical or print properties, and without stability issues during printing. PCC was ideal to illustrate this concept, as the narrow distribution characteristics of the pigment translates into increased coating pore volume. The increased coating pore volume of PCC allows the vapor to escape before blistering can occur. This results in the opportunity to use increased moisture to an advantage. The coated paper can thus be calendered at a reduced line load and still maintain the gloss target through the use of increased moisture and the ease of deformation.

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This result is rationalized as being due to the difference in macro- and micro-smoothness that different pigments impart to the coating structure. We demonstrated that narrow distribution coating PCC produces high micro-smoothness even without supercalendering. Broad distribution GCC does not give micro-smoothness to the coating, and thus gloss must be achieved through macro-smoothness via deformation of the base paper, which can only be done through harder calendering. This difference in micro-smoothness between narrow distribution PCC and broad distribution GCC directly translates to the ability of the PCC to maintain optical and physical properties at higher moisture and reduced calendering, while the GCC cannot do so.

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