

Development and production experience of the multilayer curtain-coated linerboard of Ji'an PM No. 3

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ABSTRACT: The Ji'an PM No. 3 is the first linerboard machine in China to use multilayer curtain coating technology. Since successful startup at the end of 2011, further development has been carried out to optimize running conditions, coating formulations, and the base paper to provide a product with satisfactory quality and lower cost to manufacture. The key challenges include designing the base board structure for the desired mechanical strength, designing the surface properties for subsequent coating operations, optimizing the high-speed running of the curtain coater to enhance production efficiency, minimizing the amount of titanium dioxide in the coating color, and balancing the coated board properties to make them suitable for both offset and flexographic printing. The pilot and mill scale results show that curtain coating has a major positive impact on brightness, while smoothness is improved mainly by the blade coating and calendering conditions. Optimization of base board properties and the blade + curtain + blade concept has resulted in the successful use of 100% recycled fiber to produce base board. The optical, mechanical, and printability properties of the final coated board meet market requirements for both offset and flexographic printing. Machine runnability is excellent at the current speed of 1000 m/min, and titanium dioxide has been eliminated in the coating formulations without affecting the coating coverage. A significant improvement in the total cost of coated white liner production has been achieved, compared to the conventional concept of using virgin fiber in the top ply. Future development will focus on combining low cost with further quality improvements to make linerboard suitable for a wider range of end-use applications, including frozen-food packaging and folding boxboard.

Application: Mills can refer to the cost-brightness ratio versus pigment to optimize their coating formulations to achieve desired coverage for coated paper and board.

Paper coating technology is continuing to evolve, and new application technologies are being developed to improve cost, productivity and quality. Blade coating, which had been the dominant application technology in the 1970s, was challenged in the 1990s by the premetering size press (film coating), which caused fewer coating breaks and had two-sided coating capability. Today, curtain coating is being investigated as the future coating technology because of its simultaneous multilayer coating capability [1,2], its runnability and productivity advantages, and its potential in facilitating the development of new paper grades. Curtain coating is a noncontact coating method that provides a contour coating profile, excellent coverage (as a result of its uniform coating color distribution), minimum deviation of application profiles in both the machine- and cross-directions, improved runnability (because no mechanical stress is applied to the base board), no excess coating color, and no back flow. Thus, curtain coating offers a larger operating window than blade or film coating; it also has the potential for a multilayer structure enabling the further functionalization of coated paper and board [3].

A mill scale curtain coater was installed earlier at Dong-Il in Korea to produce coated white top linerboard [4]. In this concept, the curtain coating layers made it possible to replace the virgin fiber in the top ply with recycled fiber, and, in some cases, to replace the deinked pulp under the top ply, which reduced the total cost of raw materials. The Ji'an PM No. 3, which is equipped with a multilayer curtain coater, was designed on the basis of this concept (annual production capacity about 650,000 tons). Since the successful startup at the end of 2011, further work has been carried out to improve product performance and optimize costs. The key challenges include designing the base board structure for the desired mechanical strength, designing the surface properties for subsequent coating operations, optimizing the high-speed running of the curtain coater to enhance production efficiency, minimizing the amount of titanium dioxide (TiO_2) in the coating color, and balancing the coated board properties to make them suitable for both offset and flexographic printing.

This paper presents our development work and the practical results achieved in production since the Ji'an machine startup. Some of the results were disclosed earlier in the invited presentations at TAPPI PaperCon 2012 [5,6].

TRIAL AND PRODUCTION CONDITIONS

Since the machine startup, coating formulations and coat weight distributions have gradually been optimized to get the desired coating coverage for the targeted brightness, achieve surface appearance uniformity (by eliminating colored spots in the base paper caused by recycled fibers), and obtain low surface roughness—all at acceptable cost. Because of its high refractive index, titanium dioxide has long been used by the industry to ensure good coating coverage on recycled brown fiber. Titanium dioxide is prohibitively expensive, however, so calcined clay was identified as a potential replacement.

A series of experiments was therefore run, before startup, on both the Styron (Berwyn PA, USA) pilot coater at its Center of Excellence for Paper Coating in Samstagern, Switzerland, and the Metso (Espoo, Finland) pilot coater at its Surface Treatment Technology Center in Järvenpää, Finland, and, after startup, on the Ji'an PM No. 3. The experimental parameters for these experiments follow as relates to raw materials, precoating, and pilot coater and mill production trial details.

Pilot coater trials

Raw materials of coating color

During the Styron and Metso pilot coater trials, we used Hydrocarb GCC60 (Omya International; Oftringen, Switzerland) and GCC90 (Omya International) as standard ground calcium carbonate; Capim SP clay (Imerys; Paris, France) as the standard delaminated clay; Ansilex (BASF; Ludwigshafen, Germany) as the standard calcined clay; and Kronos 2800 (Kronos; Chelmsford, MA, USA) as the standard titanium dioxide.

For precoating latex, we used a typical styrene-butadiene latex with glass transition temperature of -6.5°C , particle size of 150 nm, solid of 53%; for top-coating latex we used a typical styrene-butadiene latex with glass transition temperature of $+16^{\circ}\text{C}$, particle size 140 nm, solid 54%; multilayer emulsion 1 refers to MLE 4001 multilayer curtain-coating technology (Styron) developed to improve curtain stability; multilayer emulsion 2 refers to MLE 4112 multilayer curtain coating technology (Styron) developed to minimize crater formation.

Styron pilot coater trial

The experimental parameters for the Styron pilot coater trial were:

- Base paper: 140 g/m² recycled board with three layers made of old corrugated container (OCC) pulp produced in Ji'an
- Machine speed: 1200 m/min
- Coating sequence: blade precoating → two layers curtain coating → blade top coating
- Coating color formulations and coat weight distribution were varied across the runs
- Calender: soft nip calender
- Final board moisture: 7%

Metso pilot coater trial

The experimental parameters for the Metso pilot coater trial were:

- Base paper: 140 g/m² recycled board with three layers made of OCC pulp produced in Ji'an
- Machine speed: 1000 m/min
- Coating sequence: blade precoating → two layers curtain coating → blade top coating
- Coat weight distribution was changed across the runs:
- Blade bottom-coating layer: 80 parts ground calcium carbonate (GCC60) + 20 parts delaminated clay + 10 parts precoating latex; other additives, at the proper amounts, were kept constant
- Curtain under layer: 70 parts GCC90 + 30 parts TiO₂ + multilayer emulsion 1 + multilayer emulsion 2; other additives, at the proper amounts, were kept constant
- Curtain top layer: 70 parts GCC90 + 30 parts calcined clay + multilayer emulsion 1 + multilayer emulsion 2; other additives, at the proper amounts, were kept constant
- Blade top-coating layer: 100 parts GCC90 + 12 parts top-coating latex; other additives, at the proper amounts, were kept constant
- Calender: soft-nip calender, thermal-roll temperature 150°C, liner load at 0, 25, 40 and 55 kN/m separately
- Final board moisture: 7%

Pilot coater trial performance

Machine runnability of Styron and Metso pilot coater trials were good; coating compatibility between two curtain-coating layers and curtain stability were good. Coating color deaeration was done using a vacuum deaeration unit available for the pilot coaters.

Ji'an mill production trials

The experimental parameters for the Ji'an linerboard machine trial were:

- Base paper: 140 g/m² recycled board either with three layers made of OCC pulp, or with the top ply containing high-brightness fiber and the under-top/bottom ply made of OCC pulp
- Machine speed: 500–1000 m/min
- Coating sequence: blade precoating → two layers curtain coating → blade top coating
- Calender: soft nip calender
- Final board moisture: 7%

Ji'an trial performance

Mill production runs in Ji'an after startup were excellent. Curtain break was very rare, the curtain coating station did not need as much attention as the blade-coating station when running, and the machine has been operating very smoothly after startup.

Linerboard properties and cost calculation

Board samples before and after coating were collected in all the trials, and the following properties were tested:

- ISO brightness, as a reflection of coating coverage
- PPS surface roughness

The total raw materials cost of the coated board was calculated using typical raw materials market prices in China in the third quarter of 2012.

DATA AND ANALYSIS

Pigment system, coat weight, and coated board brightness

Pilot coater experiments were carried out to understand the impact of coat weight and pigment system on coated board brightness. Pilot rolls were run on the Styron Samstagern pilot

coater. The coating formulations and coat weight distribution are in **Table I**.

The coating coverage of a coating formulation is primarily determined by the pigments. Different pigments are known to have different coverage efficiency. Titanium dioxide provides excellent coverage as a result of its high refractive index. Calcined clay could provide good coverage by creating porosity in the coating colors (both interpigment and intrapigment pores), leading to increases in the light-scattering surfaces. Calcium carbonate (CaCO_3) and normal/delaminated clay are less efficient than TiO_2 or calcined clay. Theoretically, if we take a standard coated board with 100% GCC as the pigment in all coating layers, with a total coat weight of 30 g/m² as the reference, we could draw a simple function to link incremental coverage (measured by incremental coated board brightness over reference) to total pigment amount

Run No.		PC-I*	PC-II	PC-III	PC-IV	PC-V	PC-VI	PC-VII	PC-VIII	PC-IX
Blade bottom layer	Pigment system	80 parts GCC60* 20 parts DC*	80 parts GCC60 20 parts DC	80 parts GCC60 20 parts DC	80 parts GCC60 20 parts DC	80 parts GCC60 20 parts DC	80 parts GCC60 20 parts DC	80 parts GCC60 20 parts DC	80 parts GCC60 20 parts DC	80 parts GCC60 20 parts DC
	CW* (g/m ²)	8	8	10	10	8	11	20	8	8
Curtain under layer	Pigment system	60 parts GCC60 20 parts TiO_2 20 parts DC	80 parts GCC60 20 parts CC*	60 parts GCC60 20 parts TiO_2 20 parts DC	60 parts GCC60 20 parts TiO_2 20 parts DC	70 parts GCC60 30 parts TiO_2	50 parts GCC60 50 parts CC	50 parts GCC60 50 parts CC	50 parts GCC60 50 parts CC	50 parts GCC60 50 parts CC
	CW (g/m ²)	6	6	6	6	10	8	8	8	7
Curtain upper layer	Pigment system	70 parts GCC60 30 parts CC	70 parts GCC60 30 parts CC	45 parts GCC60 55 parts CC	70 parts GCC60 30 parts CC	55 parts GCC60 45 parts CC	55 parts GCC60 45 parts CC	50 parts GCC60 50 parts CC	50 parts GCC60 50 parts CC	50 parts GCC60 50 parts CC
	CW (g/m ²)	8	8	8	8	6	8	8	8	7
Blade top layer	Pigment system	100 parts GCC90	100 parts GCC90	100 parts GCC90	100 parts GCC90	100 parts GCC90	100 parts GCC90	100 parts GCC90	100 parts GCC90	100 parts GCC90
	CW (g/m ²)	10	10	10	8	11	8	8	16	13
Base board brightness (%)		15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Coated board brightness (%)		77.0	77.2	83.1	79.2	81.4	83.7	86.1	81.5	80.0
Relative cost (%)		100.7	96.2	102.8	101.2	109.7	100.0	102.2	101.1	98.9
*PC-I to PC-IX, pilot coater trial (PC) run number; GCC = ground calcium carbonate; DC = delaminated clay; CW= coat weight; CC = calcined clay.										

I. Pigment system, coat weight, coated board properties, and relative cost of runs in the Styron pilot coater trial.

COATING

in the coating layer (Eq. [1]):

$$\text{Brightness of coated board} = \text{incremental CaCO}_3 \text{ amount} \times \text{coverage efficiency_CaCO}_3 + \text{pigment A total amount} \times \text{incremental coverage efficiency_Pigment A} + \text{Pigment B total amount} \times \text{incremental coverage efficiency_Pigment B} + \dots + \text{brightness of reference board} \quad (1)$$

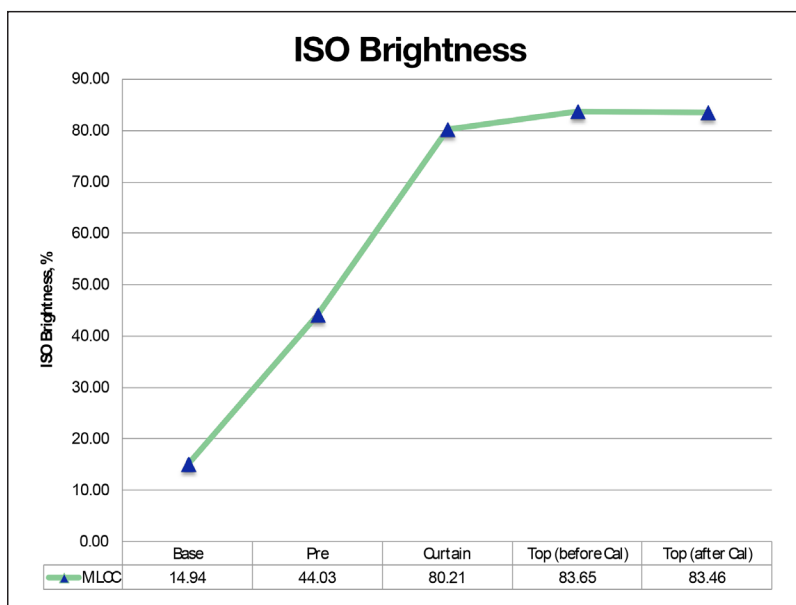
where

incremental coverage efficiency_Pigment A refers to the incremental coverage that Pigment A could provide over the GCC; *incremental CaCO₃ amount* is calculated by first multiplying dry parts of such pigment in coating formulations of each coating layer by coat weight of such layer, summing up all the layers and subtracting the amount in reference board; and *Pigment A total amount* is calculated by multiplying dry parts of such pigment in coating formulations of each coating layer by coat weight of such layer, and summing up all the layers. The same applies to other pigments except CaCO₃.

Using this simple equation to do a linear regression on the data listed in Table I, we get Eq. (2) (R-square is 0.92):

$$\text{Brightness of coated board} = \text{delaminated clay} \times 1.3 \times 10^{-2} + \text{calcined clay} \times 1.5 \times 10^{-2} + \text{titanium dioxide} \times 2.3 \times 10^{-2} + 68.3 \quad (2)$$

From Eq. (2), it could be concluded that TiO₂ provides the best coverage efficiency (the highest incremental coverage over the GCC), followed by calcined clay and then delaminated clay. However, this very simple model does not take account of other factors such as coating structure and pigment distribution in the different layers.



1. ISO brightness development after coating layers application; data from pilot coater trial run of PC-VI in Table I.

Brightness development

The typical brightness development after a coating application is shown in **Fig. 1**. The coating formulations and coat weight distribution are taken from a run of PC-VI in Table I. It is clear from the brightness development curve that the curtain layer is very effective in increasing coverage, due partly to the pigment system used and partly to its effectiveness in providing a contour coating. The bottom blade coating provides certain coverage as well. ISO brightness higher than 80% could meet the general industrial requirement for coated white top linerboard.

Base paper and coated board brightness

Base paper brightness is known to have a direct impact on coated board brightness. Generally speaking, the higher the base brightness is, the less coating color coverage is required to achieve the target brightness, which provides an opportunity to further optimize coating formulations and coat weight distribution. This has been studied in Ji'an production. The detailed coating formulations, coat weight distribution, brightness, and relative costs are listed in **Table II**.

It could be concluded from Table II that, after changing to a higher brightness base, it is possible to reduce the coat weight of the curtain coating layer, while still achieving similar or slightly improved coated board brightness. It is also worth mentioning that, even at a lower calcined clay level and reduced coat weight, the production results show that curtain coating is crucial to getting the desired coverage that will prevent color spots in the base paper from showing through.

PPS and coat weight distribution

Parker Print Surf (PPS) is also a very important property for coated white top linerboard. It is generally accepted that lower PPS surface roughness value is favored for coated linerboard, allowing good printability. In view of the claim that curtain coating provides very good coverage but does not provide as smooth a surface as blade coating (due to lack of metering pressure), the study on improving surface roughness is very relevant. Before the machine start-up, a pilot coater trial was carried out on the Metso pilot coater in Finland, with the aim of studying the impact of total coat weight and coat weight distribution on PPS surface roughness and on the coated board brightness value. Coating color formulations were kept constant across the runs.

PPS surface roughness, brightness, total coat weight, and coat weight distribution results were plotted in **Fig. 2**. It could be concluded that curtain coat weight has a significant impact on final coated board brightness—the higher the curtain coat weight, the higher the brightness.

Run No.		MP-I*	MP-II	MP-III	MP-IV	MP-V	MP-VI	MP-VII	MP-VIII	MP-IX
Blade bottom layer	Pigment system	90 parts GCC60* 10 parts DC*	90 parts GCC60 10 parts DC	90 parts GCC60 10 parts DC	90 parts GCC60 10 parts DC	90 parts GCC60 10 parts DC	90 parts GCC60 10 parts DC	90 parts GCC60 10 parts DC	90 parts GCC60 10 parts DC	90 parts GCC60 10 parts DC
	CW* (g/m ²)	14	13	11	12	12	11	11	11	11
Curtain under layer	Pigment system	52 parts GCC60 48 parts CC	52 parts GCC60 48 parts CC	52 parts GCC60 48 parts CC	52 parts GCC60 48 parts CC	73 parts GCC60 27 parts CC	73 parts GCC60 27 parts CC	73 parts GCC60 27 parts CC	73 parts GCC60 27 parts CC	73 parts GCC60 27 parts CC
	CW (g/m ²)	8	8	7.5	7	6	5.5	5.25	5	5
Curtain upper layer	Pigment system	52 parts GCC60 48 parts CC	52 parts GCC60 48 parts CC	52 parts GCC60 48 parts CC	52 parts GCC60 48 parts CC	73 parts GCC60 27 parts CC	73 parts GCC60 27 parts CC	73 parts GCC60 27 parts CC	73 parts GCC60 27 parts CC	73 parts GCC60 27 parts CC
	CW (g/m ²)	8	8	7.5	7	6	5.5	5.25	5	5
Blade top layer	Pigment system	100 parts GCC90	100 parts GCC90	100 parts GCC90	100 parts GCC90	100 parts GCC90	100 parts GCC90	100 parts GCC90	100 parts GCC90	100 parts GCC90
	CW (g/m ²)	9	9	11	10	11	11	11.5	11.5	11
Base board brightness (%)		15.2	16.5	19.7	21.1	53.7	54.4	60	61	62
Coated board brightness (after calendering)(%)		81.8	81.7	81.5	81.6	81.3	81.8	82.4	82.0	82.5
Base board PPS roughness (μm)		11.5	11.3	11.4	8.7	10.0	9.3	7.0	6.8	7.0
Coate board PPS roughness (μm)		2.1	2.0	1.8	1.6	1.7	1.8	1.9	1.8	1.7
Relative cost (%)		100.9	100.7	99.9	99.2	102.0	101.4	100.8	100.6	100.4
*MP-I to MP-IX, mill production (MP) run number; GCC = ground calcium carbonate; DC = delaminated clay; CW= coat weight; CC = calcined clay.										

II. Mill production details: base paper brightness, coating formulations, coat weight distribution, coated board brightness, and relative cost of each mill run.

Coat weight and coat weight distribution have an impact on coated board PPS surface roughness. The precoating conditions, in particular, have a major effect on final smoothness—and a much more positive effect than the top blade coating coat weight. This indicates that the blade precoating layer has a filling-in effect that results in smoother board, which is beneficial for a subsequent curtain coating application. Thus, the trial point without blade precoating has the highest final PPS roughness value, even if the total coat weight is the same (multilayer curtain 19 g/m² + blade 16 g/m²; total 35 g/m²).

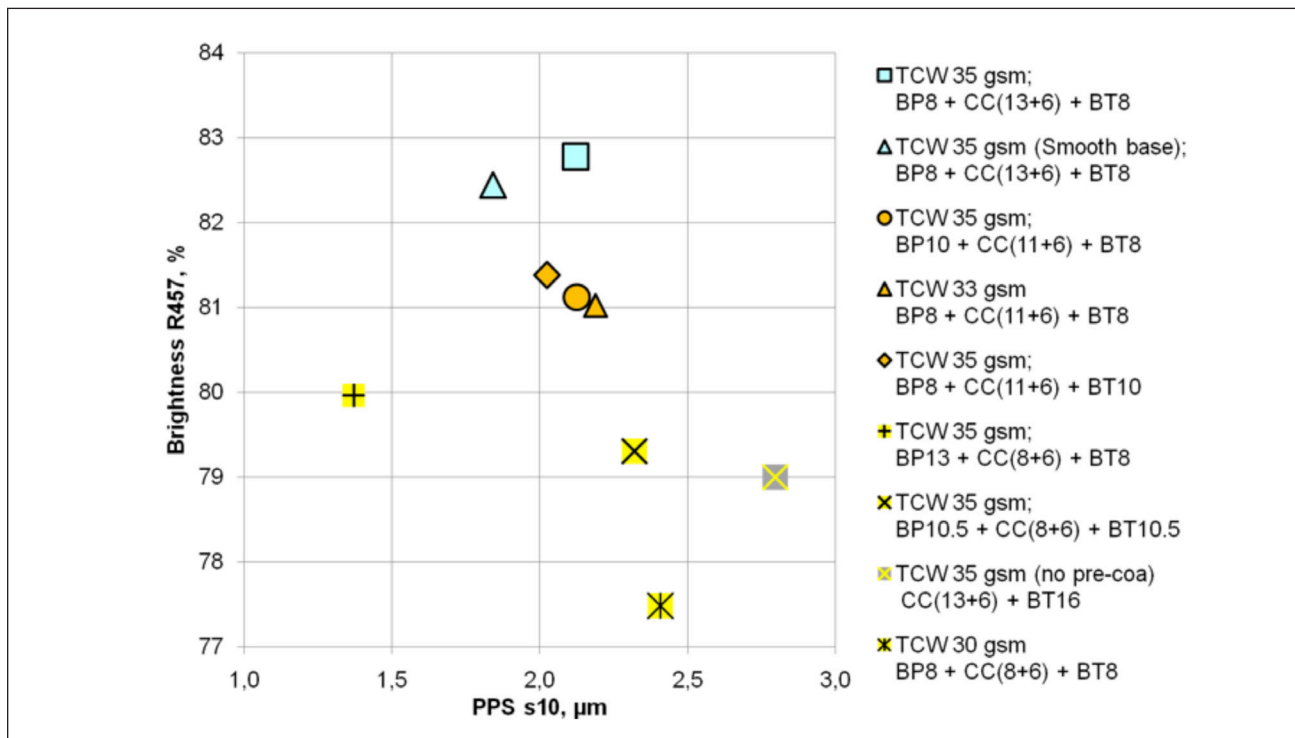
The lowest PPS roughness was reached with a high blade precoating coat weight (13 g/m²). The high coat weight of 13 g/m² was applied with a bent blade coating mode, where-

as lower coat weight was applied with a stiff blade coating mode. This might indicate that bent-blade precoating is also beneficial for final smoothness.

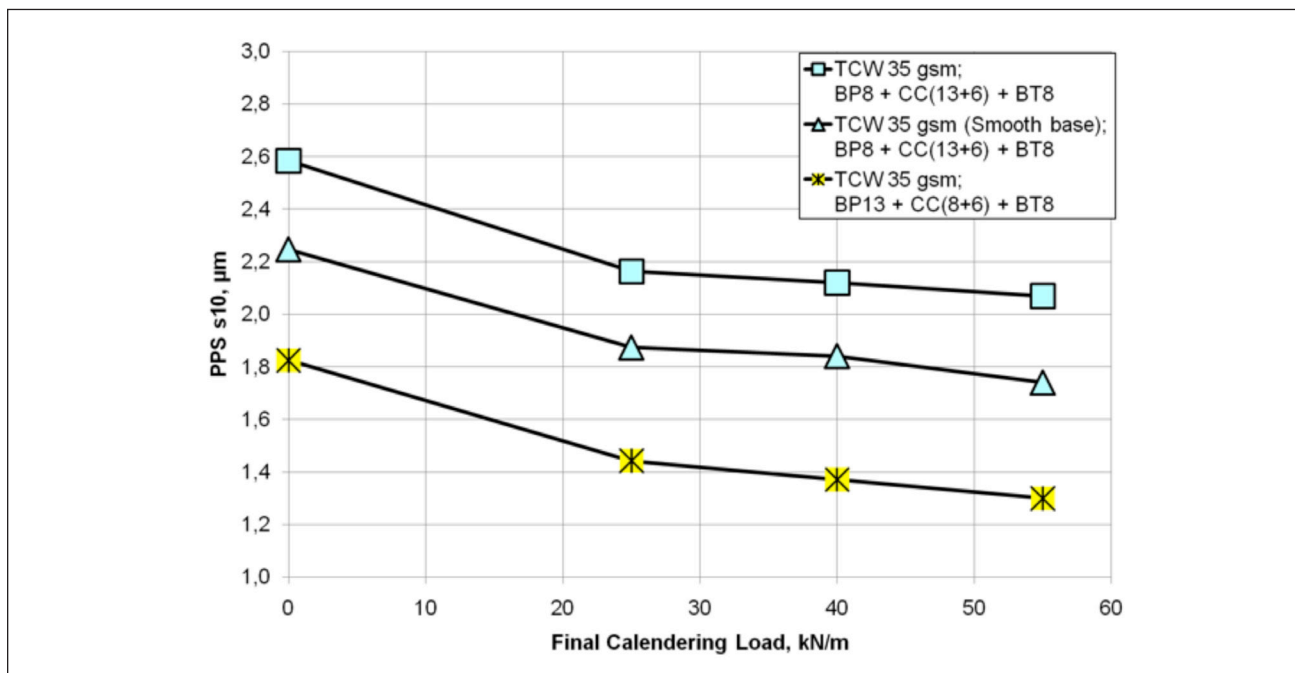
PPS and calendering conditions

Both precalendering and final calendaring decrease the PPS roughness value of the final coated product (**Fig. 3**). In this trial, the final product's PPS roughness decreased by 0.3–0.4 μm, whereas the base board surface Bendtsen roughness decreased from 500 mL/min to less than 300 mL/min. Base board smoothness was improved by increasing the load of the hot hard nip whose surface temperature was 120°C. Earlier studies [7,8] had also shown the positive effect of precalender-

COATING



2. Impact of total coat weight and coat weight distribution on Parker Print Surf (PPS) surface roughness and coated board ISO brightness value; final calendar load 40 kN/m. (*TCW 35—total coat weight 35 g/m²; BP8—blade precoating, coat weight 8 g/m²; CC (11 + 6)—two curtain-coating layers coat weight: under layer 11 g/m², upper layer 6 g/m²; BT8—blade top coating, coat weight 8 g/m²).



3. Effect of precalendering and final calendaring on PPS roughness of final product. (TCW 35—total coat weight 35 g/m²; BP8—blade precoating, coat weight 8 g/m²; CC (13 + 6)—curtain coating layers coat weight: under 13 g/m², upper layer 6 g/m²; BT8—blade top coating, coat weight 8 g/m²). Bendtsen roughness of base board was about 500 mL/min, while smooth base was about 300 mL/min.

ing. However, precoating is even more effective than hot hard nip precalendering in creating smoothness. On the other hand, an increased amount of blade precoating had a negative impact on brightness (Fig. 2). This is because the total coat weight was kept the same (35 g/m²) and the curtain coat

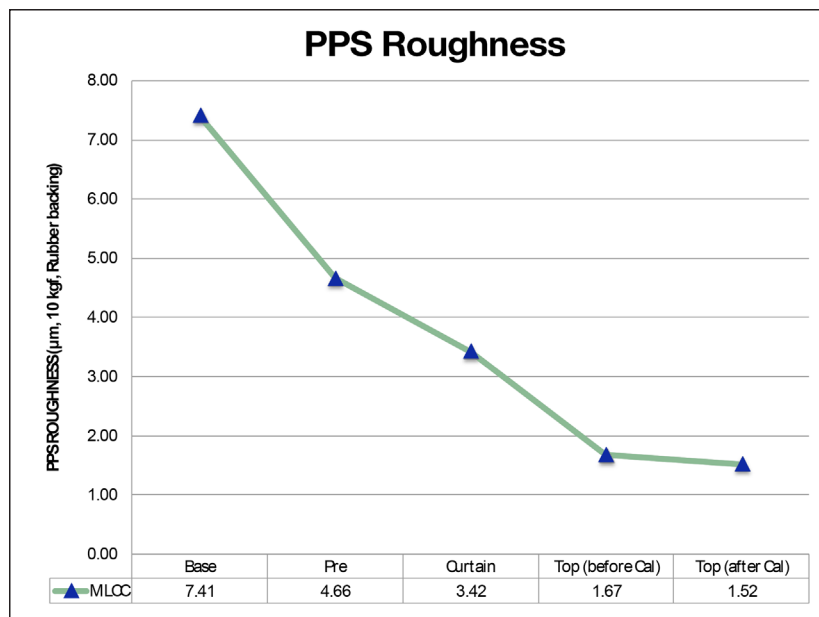
weight was decreased. Precalendering decreased the PPS roughness without sacrificing brightness (Fig. 2).

PPS development during coating

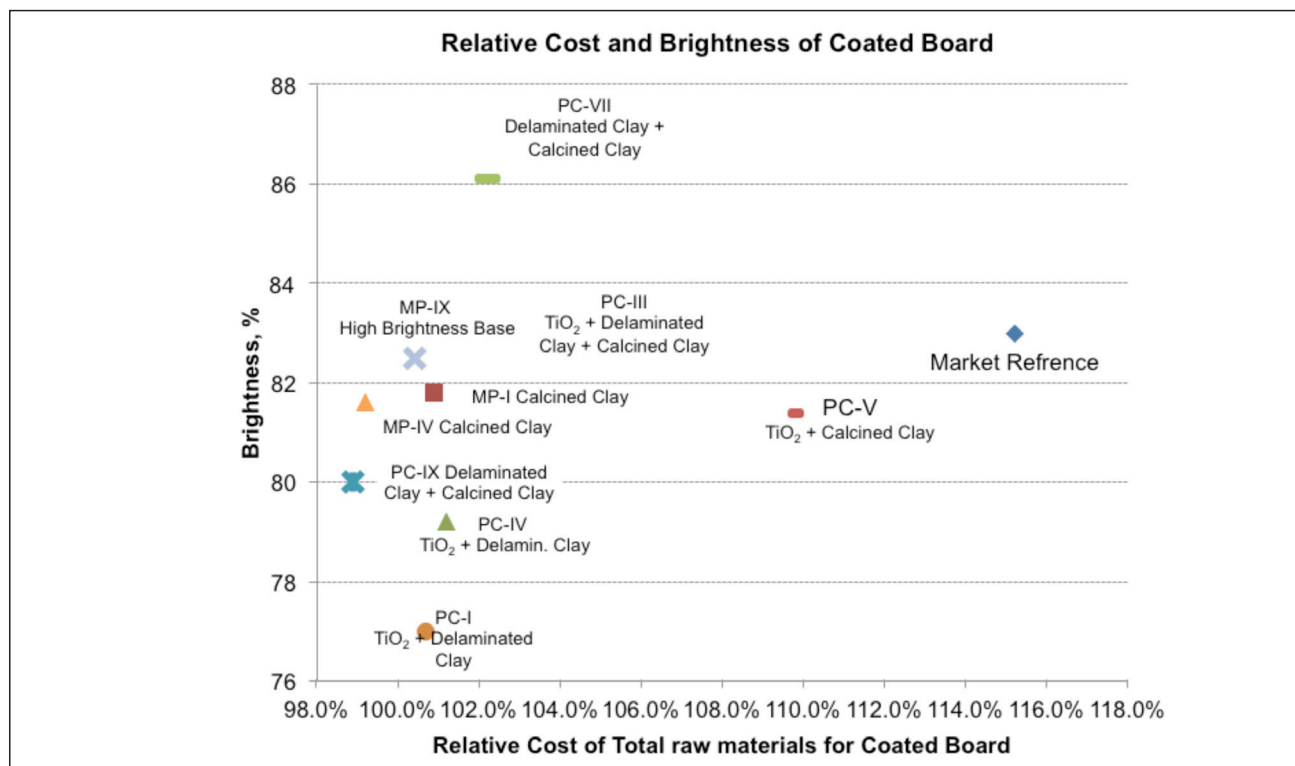
During the pilot coater trial, PPS surface roughness development was also tested and plotted in **Fig. 4**. The coating formulations and coat weight distribution are taken from run of PC-VI run in Table I. It can be seen that every coating layer has a certain impact on PPS reduction; PPS drops by 2.5 μm after the blade bottom-coating application and by another 1.2 μm after the curtain coating layer application. Top coating reduces the PPS further by 1.7 μm , while calendering contributes another 0.15 μm .

Coated board cost

Cost is always an important consideration for a new curtain coater approach to produce white top linerboard. The pigment system in coating color, coat weight, and base board jointly determines the total raw materials cost. Making a linear regression between coverage (brightness difference between coated board and base board)/cost (\$/metric ton coated board) and the



4. PPS surface roughness development after each coating layer application, and after calendering; data from pilot coater trial run of PC-VI in Table I.



5. Relationship between cost and brightness of coated board using different production approaches. The designation before each item shows the formulation and run details (for example, PC-I represents the PC-I run in Table I and MP-IX represents the MP-IX mill production run in Table II).

COATING

pigment system, using the pilot coater trial data listed in Table I, we arrive at Eq. (3):

$$\text{Coverage (brightness difference between coated board and base board)} / \text{cost} = 57.8 - 2.1 \times 10^{-3} \times \text{incremental CaCO}_3 \text{ amount} + 8.9 \times 10^{-3} \times \text{delaminated clay amount} + 9.7 \times 10^{-3} \times \text{calcined clay amount} - 5.9 \times 10^{-3} \times \text{TiO}_2 \text{ amount} \quad (3)$$

where

incremental CaCO₃ amount is calculated by first multiplying dry parts of such pigment in coating formulations of each coating layer by coat weight of such layer, summing up all the layers, and subtracting the amount in reference board; *delaminated clay amount* is calculated by multiplying dry parts of such pigment in coating formulations of each coating layer by coat weight of such layer and summing up all the layers. The same applies to other pigments except CaCO₃.

From Eq. (3), it can be concluded that TiO₂ and GCC are

less efficient in terms of improving coverage and cost ratio than calcined clay and delaminated clay. This again shows the feasibility and necessity of using alternative pigments to replace TiO₂ from the cost-performance balance perspective. If we include the mill production data and compare with the coated white top-linerboard market reference, using bleached pulp in the top ply and some portion of deinked pulp in the under-top ply, we can conclude the following (as shown in **Fig. 5**.) in terms of coated board brightness and coated board total raw materials cost.

From the graph in Fig. 5, we can conclude that, by using a curtain coater and thus enabling the use of recycled fiber in base board, it is possible to significantly reduce coated board raw materials cost. It is also clear that a system based on calcined clay can provide better cost performance than titanium dioxide in terms of coverage and cost balance. Using a high brightness base, it is possible to further optimize coating formulations with a similar cost, versus coating directly on a brown base.

ABOUT THE AUTHORS

Curtain coating has attracted much attention in the paper coating industry given its advantages in coverage, operational convenience, and the possibility for developing functional paper and board grades. Of special interest to the paper industry is how to use the curtain coater to produce coated linerboard that performs satisfactorily while maintaining lower raw materials cost than market reference using virgin fiber and blade coaters.

Our intention was to perform a systematic investigation into coating-color optimization and implementation in mill-scale production to provide an industrial reference for further development of curtain coating.

Some research has been done on curtain coating in terms of the coater runnability, coating coverage, and coating structure. That research benefited our current work to a great extent in terms of providing theoretical fundamentals to designing and optimizing coating formulations and coater running parameters. However, this research provides the first reference on large-scale (machine width about 7.25 m) and high-speed (design speed about 1200 m/min) curtain coaters for coated linerboard.

The difficult aspect was implementing the development work in the laboratory (pilot coater) to mill scale production. We addressed this through great teamwork among Styron, Metso, and the Ji'an operation team.

When an output is influenced by many inputs, performing a systematic study and establishing a model to understand the influence of each factor is very



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powerful. The surprising finding in this research is that coating clay, especially calcined clay, provides a very effective coverage when used in coating color, compared with calcium carbonate and titanium dioxide, in terms of cost and brightness balance.

The model that we established on linking coverage and pigment mix, and cost-brightness ratio versus pigment mix is a useful reference for paper mills to optimize their coating formulations to achieve desired coverage for coated paper and board. Future development will focus on combining low cost with further quality improvements to make the coated linerboard produced with double-layer curtain coater suitable for a wider range of end-use applications, including frozen food packaging and folding boxboard.

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CONCLUSIONS AND RECOMMENDATIONS

The conclusion to be drawn from the various development activities before machine startup, and from the production results after startup of the Ji'an PM No. 3, is that it is possible to produce coated white top linerboard that meets market requirements with 100% recycled fiber and a TiO_2 -free coating formulation. Calcined clay and delaminated clay, used in combination, provide better cost performance in terms of coating coverage than does TiO_2 . To improve PPS roughness, blade coat weight is critical, and it is beneficial to have a blade bottom-coating layer. Increasing the base-paper brightness would further help to optimize coating formulations in terms of a lower coverage requirement, but would not necessarily provide a cost advantage over coating on a brown base. It is also possible to improve the final smoothness of coated board by optimizing the precalendaring and final calendaring with a top liner. **TJ**

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