Comparison of the Surface and Print Quality of Curtain and Blade Coated Papers

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Abstract

Curtain coating is non-contact pre-metered coating process, which offers great potential for improved coverage at lower coat weights for the coated paper industry. Absence of shear and hydrostatic force leads to differences in coating-basesheet interactions and process dynamics currently experienced with other conventional coating processes. These differences may lead to surface characteristics of curtain coated papers that are very different from those obtained by conventional coating methods. Due to these differences, printing attributes of curtain coated papers are crucial to their acceptance in the marketplace. Due to the absence of shear, pigment alignment is not as strong as in other conventional coating processes. In addition, as there is little hydrostatic pressure, binder migration is minimal, so more binder is present at the surface. The increase in binder at the surface improves the interaction of the coating layer with the ink, resulting in a thicker layer of ink transfer to the base sheet in offset printing.

In this study, the calendering response, printability and surface of curtain coated papers were compared with blade coated papers at equal coat weights and surface roughness. An uncoated commercial light weight basesheet was curtain coated at Mitsubishi Heavy Industry's state of the art coating research center in Hiroshima, Japan and blade coated on a cylindrical laboratory coater, CLC 6000, at 4.8 and 5.8 gsm (C1S). The samples were supercalendered to identical number of passes and pressure and temperature, and then printed with black ink, using a Hamada conventionally dampened sheetfed offset press. The calendering response, print density and print mottle were measured. Surface attributes were compared by SEM and AFM measurements.

The calendering response of curtain coated paper was found to be typical of contour coated surfaces. The print densities of the curtain and blade coated papers were found to be comparable; although the print densities of the curtain coated papers were slightly higher. The print mottle of the curtain coated papers was much higher. A possible explanation of observations is; higher micro roughness of curtain coated papers results in higher immobilized layer of ink in offset printing, which in turn results in higher but non uniform ink transfer. AFM measurements indicated that the curtain coated papers have higher amounts of binder on the surface, with virtually no pigment alignment. The higher amount of binder on the surface was attributed to the porous structure of coating lattice, which facilitated binder migration to the surface during drying.

Keywords: Contour, Ink film split, micro roughness, solvent absorption, Binder distribution, pigment alignment**.**

1 Introduction

Curtain coating [1-7] is a non-contact pre-metered contour coating operation offering great potential for the coated paper industry (Figure 1). Absence of shear and hydrostatic forces leads to very different coating-basesheet interactions and process dynamics than seen in other conventional coating processes.

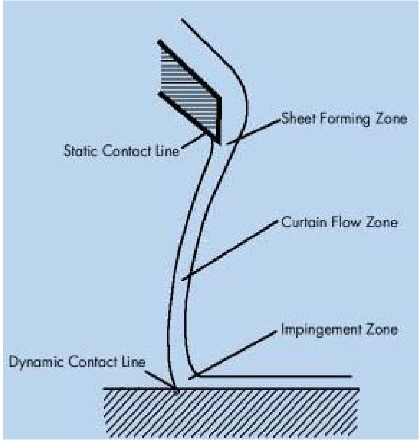


Figure 1: Curtain coating operation(2)

These differences may lead to surface characteristics that are very different from conventional coating processes, which may, in turn, lead to substantial differences in their printing properties. The influence of paper attributes on offset printing is well studied. The ink film split in offset printing is governed by ink-paper interactions [8]. These interactions are influenced by paper attributes such as topology i.e. micro and macro roughness, oil absorbency i.e. chemistry and pore size distribution. These paper properties are, in turn, strongly influenced by paper coating methods, which, due to their unique process dynamics, differ in surface development; contour or surface coating; binder migration and particle packing. In curtain coating, due to the absence of shear during metering, pigment alignment is not as strong as in other conventional coating processes (9). In addition, as there is little hydrostatic pressure, coating and binder penetration into the base sheet is minimal, so more binder is expected to be present at the surface. An enhanced amount of binder at the surface would influence the interaction of the coating with the fountain solution and ink during the offset printing process. This may result in differences in the amount and uniformity of ink transfer during printing.

1.1 Pigment Alignment

The pigment alignment [9] on a coated surface profoundly influences its optical and printing properties; opacity being one of the most important for lightweight coated papers. Pigment alignment is strongly influenced by the shear experienced during application and metering (Figure 2).

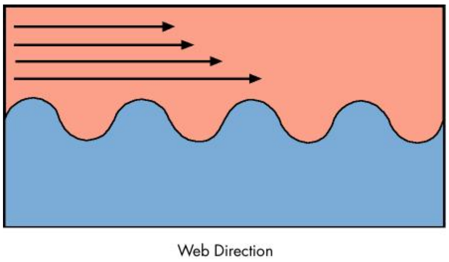


Figure 2: Development of shear at the impingement zone.

Curtain coating is a low shear operation. Coating flow in the die is of low shear and low Reynolds number; whereas flow in the film formation zone is extensional. As a result, there will be little particle alignment in the film formation zone as the curtain is stretched. In high speed curtain coating, as the slow moving curtain impinges on the faster (10-20 times) moving substrate, it is dragged forward. This sudden drag creates a shear field as shown in Figure 2, which is greatest in the immediate vicinity of the impingement zone (3), giving rise to a boundary layer (applying lubrication theory). The maximum shear in the curtain coating process is available in this zone and is strongly dependant on the curtain and substrate velocity difference. Therefore, most of the particle alignment takes place in this region. The amount of shear can be controlled by the ratio of the curtain velocity to web speed [2].

1.2 Shape of the Curtain Coated Surface

Curtain coating can be understood as a lamination process, where a wet film is laminated on to the surface of a substrate [2-6]. As the curtain wets the basesheet (Figure 3a), there are several scenarios that may develop depending on the roughness scale of the basesheet (see Figure 3). If the roughness is of low amplitude and low frequency, the curtain will follow the contour of the paper (Figure 3b). If the roughness is of high amplitude and high frequency, it will coat on the peaks of the surface and upon drying, the shrinkage of the coating will cause the coating to retract to the corners, leaving a crater defect (Figure 4c). Incomplete contouring is illustrated in Figure 3d.

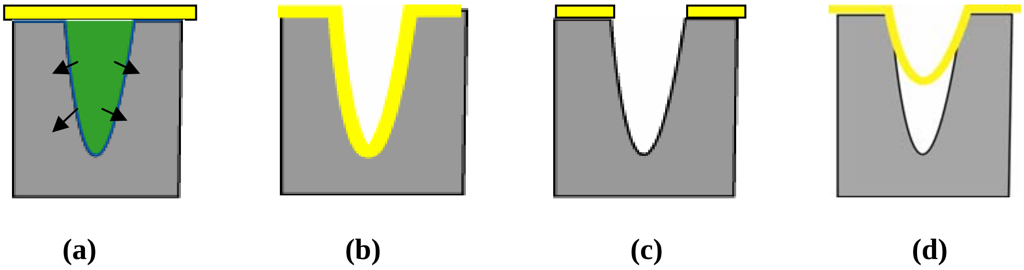


Figure 3: Various scenarios on curtain wetting of substrate (a) initial wetting (b) contour (c) classic crater (d) incomplete contour following.

1.3 Binder Migration

Binder migration affects gloss, smoothness, mottle and print quality. The amount of binder present at the surface, affects the interaction of the coating with fountain solution and ink [8]. Coating processes affect migration as they apply varying amounts of hydrostatic pressure during application and metering. Curtain coaters impart little or no hydrostatic pressure, so binder migration is minimal.

Binder migration under drying conditions presents a different scenario. During drying, some binder follows the path of water vapors and is affected by factors such as hydrophobicity, coating lattice compaction (or lack of it), drying rate and orientation of particles. As there is little hydrostatic force to facilitate compaction of coating layer in the curtain coating process, the resultant coating lattice is porous. In addition, as there is absence of strong shear, high aspect ratio pigments (such as clays and PCC) are not well aligned. A porous coating layer and variable orientation of pigments facilitates binder migration to the surface in curtain coating. Furthermore, the low hydrostatic pressure also tends to leave more binder near the surface relative to other coating processes.

1.4 Calendering Response

Calendering is an important operation to improve the smoothness and gloss of paper [10]. The calendering response determines the properties of the paper surface and is influenced by the coating formulation, coating process and the type of calendering itself. Figure 4 shows the differences in basesheet densification and surface smoothness profiles of super and hot-soft nip calendered papers. Due to the higher pressures and roll hardness of supercalenders, supercalendered papers are densified more than with hot-soft nip calendars, as the surface profiles are flattened. Hot-soft nip calenders utilize heat to enable less pressure to be used to improve the surface profiles. The soft roll is deformable, resulting in a more even pressure profile in the nip and less sheet densification of the higher caliper areas of the sheet. Due to these differences, the calendering conditions required to obtain a desired smoothness is closely related to the calendering response of the coating layer [10].

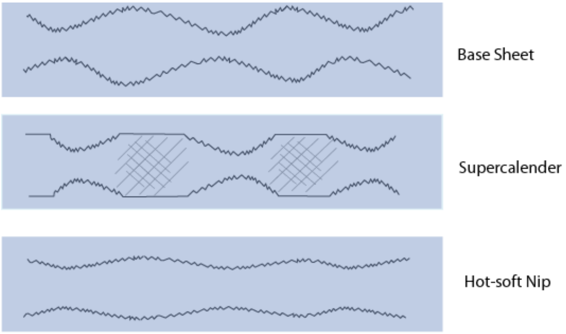


Figure 4: Calendering response of super and hot-soft nip calendaring [10].

The coating process also affects the calendering response, as it strongly influences the physical (surface type) and chemical (binder concentration) properties of the surface. The glass transition temperature (T_g) of the latex and bulk of the paper are the coating color and base sheet contribution, respectively to the calendaring response. Curtain coating is a true contour coating method.

2 Objective

In this study, differences in print quality, pigment alignment, and binder distribution of curtain coated papers were compared to blade coated papers after printing on a one color sheetfed offset duplicator press.

3 Experimental

An uncoated light-weight commercial base sheet (42 gsm) was curtain (Mitsubishi heavy industries, Hiroshima Japan) and blade coated at 1200 MPM (CLC 6000, Western Michigan University) at 4.6 and 5.7 gsm (C1S). The coating was a typical offset formulation (see Table 1) at 54% solids. The coated samples were then supercalendered at 1500 PLI (4 passes) with no heating. The calendering response was measured with a Parker Print Surf (PPS) roughness instrument. The samples were then printed with black ink on a single color HAMADA sheetfed conventionally dampened offset press. Print density was measured using an X-Rite densitometer. Mottle was measured by image analysis using Verity IA software [11]. To understand and explain the differences in print quality, AFM and SEM measurements [9, 12-14] were performed to observe the alignment of the pigment and distribution of binder in the coating layer.

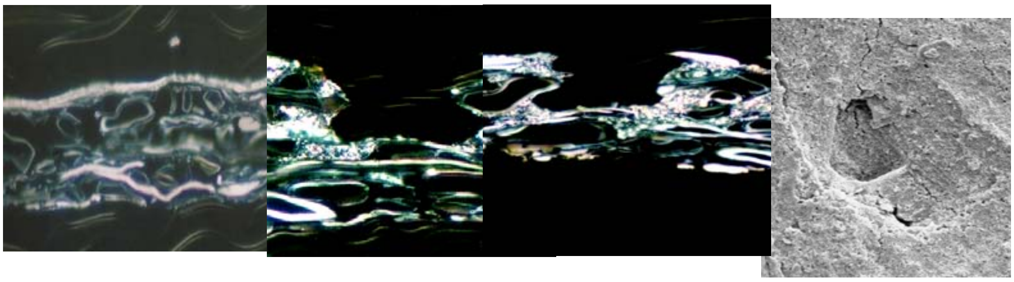
Table 1: Coating Formulation

	Carbonate	Clay	SBR latex	CMC	Lubricant	Surfactant
Name	Carbital 90	Ultra white 90	CP 620 NA	Cellogen PR	Nopcote 104	Niaproof-4
pph	60	40	12	0.45	0.6	0.20

4 Results and discussion

4.1 Comparison of Surfaces

Figure 5 shows the z direction cut of curtain coated paper. The figure confirms the scenarios for curtain coating as discussed in Figure 3. At low amplitude and frequency roughness variation of paper, the curtain follows the contour of the paper (a). For a high amplitude and frequency roughness scale, the curtain may coat on lower and upper part (b) or form a classical crater (c). As discussed in the previous session, the curtain may also partially wet the surface, which on calendering will show up as surface cracks (d).

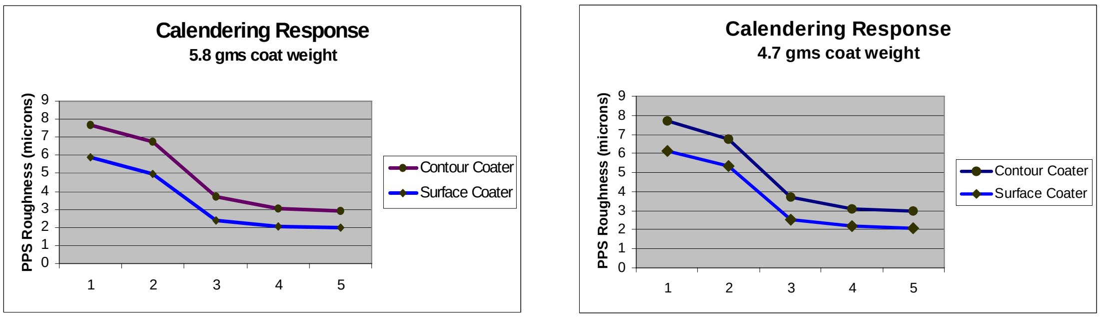


(a) (b) (c) (d)

Figure 5: Z-direction cut of curtain coated paper and the surface.

4.2 Calendering Response

Figure 6 shows the response of curtain and blade coated papers to calendering. The comparison is typical of contour and surface coated papers. The curtain coated, calendered paper remains slightly rougher regardless of the number of nips experienced. For both papers there was a significant drop in roughness after the second pass through the nip. Little or no improvement in smoothness was obtained after the 3rd pass.

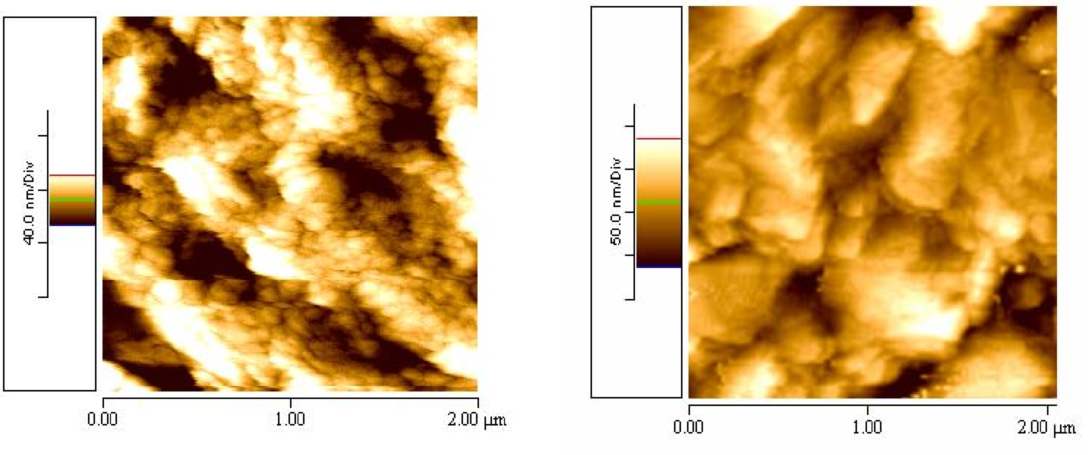


(a) (b)

Figure 6: Calendering response of curtain and blade (surface) coated papers.

4.3 Surface of Curtain and Blade Coated Paper

Figure 7 shows selected AFM images of curtain and blade coated papers. Based on the authors' previous experience [15], the "grape-like" clusters are probably uncoalesced SBR latex particles dispersed in the coalesced uniform phase. The pigments are likely seen as the larger particles of varying shape and size [15].

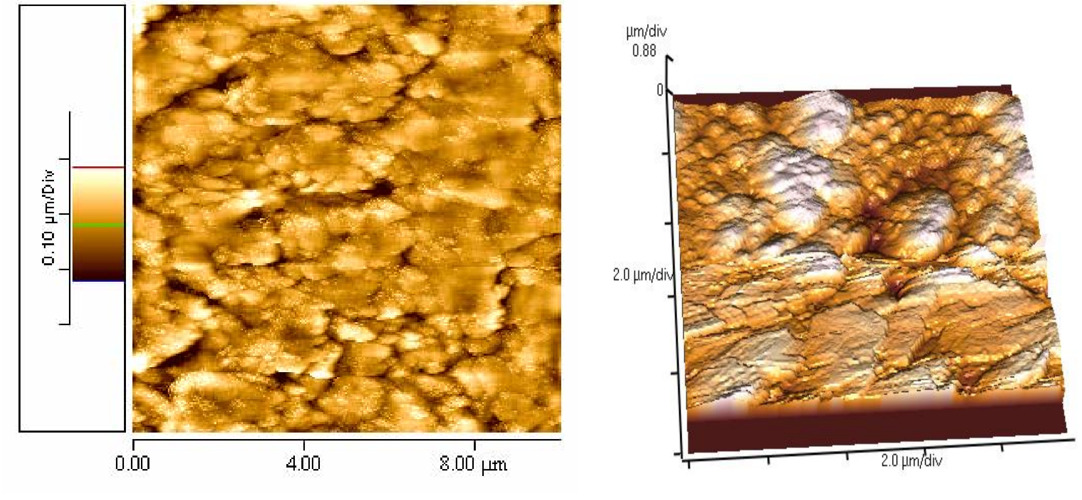


(a) **(b)**

Figure 7: Atomic force micrograph (AFM) of curtain (a) and blade (b) coated papers showing SBR latex.

Thus, it is likely from Figure 7 that much more latex is on the surface of the curtain coated paper than for the blade coated paper. There appears to be little binder on the surface of the blade-coated samples. The only apparently visible SBR latex on the blade-coated papers is present in the microcontours of the basepaper that do not come in contact with the blade. The binder distribution on the curtain-coated paper appears to be uniform throughout the surface.

Figure 8 indicates the alignment of the coating pigments in the curtain and blade coated papers. In the blade coated paper, not only are the high aspect ratio clay particles aligned (flat) prominently, but also overall, the surface is much more compact. For the curtain coated paper, the clay particles appear to be almost random and the coating structure seems to be noticeably more open. The orientated (flat) high aspect ratio pigments hinder binder migration during drying.



(a) **(b)**

Figure 8: Atomic force micrograph curtain (a) and blade (b) coated papers showing alignment of clay particles.

The results indicate that curtain coating forms a much more open coating lattice, due to the random alignment of pigment in the absence of significant shear and hydrostatic pressure. Such an open structure of the coating lattice facilitates binder migration during drying, resulting in a much higher concentration of SBR latex on the surface of the curtain coated papers than the blade coated papers.

Figure 9 shows SEM pictures of calendered and uncalendered curtain and blade coated papers at 700X and 7000X magnifications. Many surface pores are visible on the curtain coated coating layer (a) and (b). This suggests that the coating lattice is very open and there is no compaction of the coating layer, as is common in blade and rod coated papers. There is some loss of openness of the structure on calendering, but the structure remains very porous, nonetheless (c) and (d). The blade coated coating layer (e) and (f), on the other hand, is almost completely closed with only few surface pores visible on the surface. Thus, the blade coated surface is "closed".

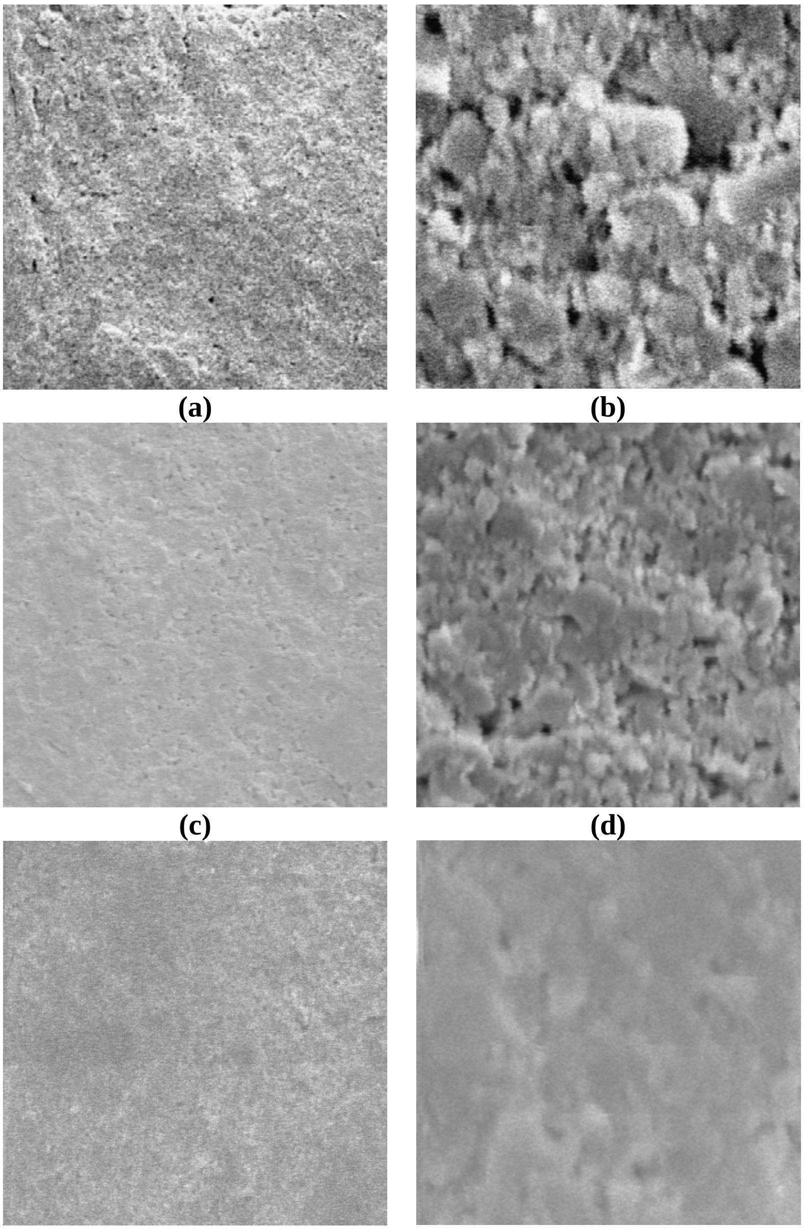
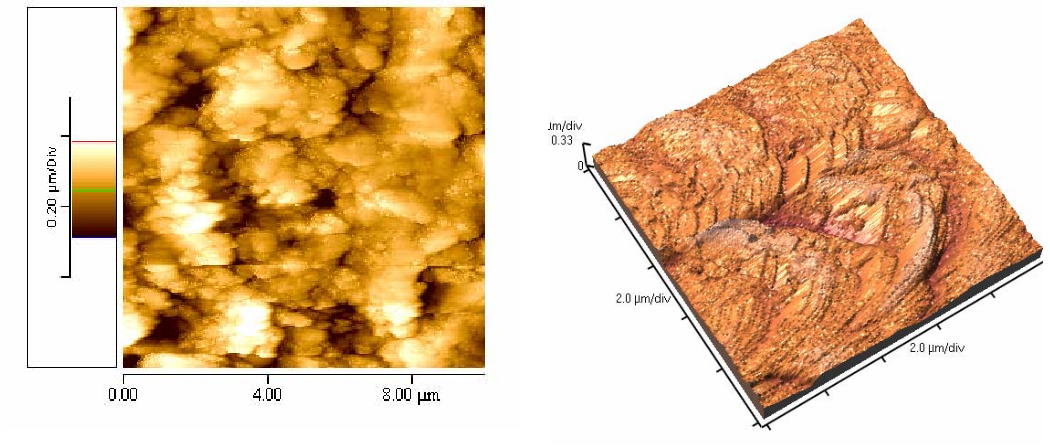


Figure 9: Scanning electron micrograph (SEM) at 700X and 7000X magnification of Curtain coated-uncalendered (a) and (b), Curtain coated – calendered (c) and (d) and Blade coated calendered (e) and (f) respectively.

This interpretation is consistent with the AFM surface topography shown in Figure 10.

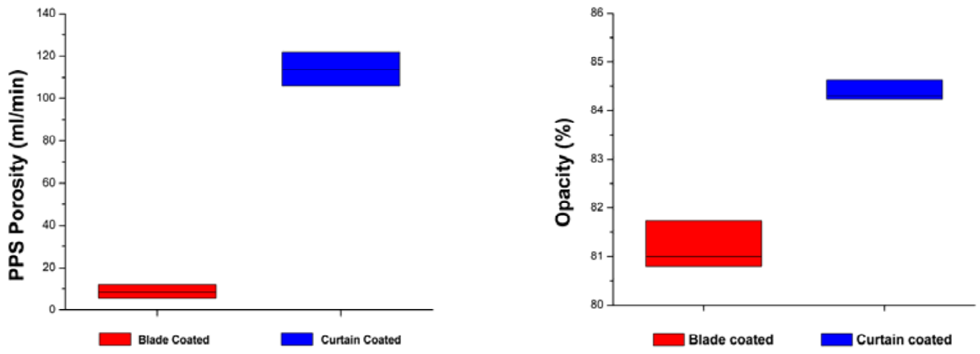


(a) **(b)**

Figure 10: AFM showing porous layer for curtain coated and a nonporous "closed" layer of blade coated paper.

Those differences in surface topography are also reflected in air permeability (PPS porosity) and opacity (Figure 11). Indeed, Pal et al [16] has shown the Darcy permeability, of dimensions of area, can be calculated from the PPS porosity. Thus, the air permeability, a measure of exposed pore area of the surface to fluid flow, of the curtain coated layer is an order of magnitude larger than that of the blade coated layer for the same coat weight. This corresponds to an effective pore throat diameter that is about a factor of 3 larger for the curtain coating than for the blade coating. This can be accounted for by the imperfect alignment of clay plates and carbonate blocks (GCC). The air permeability is strongly dependent on pigment alignment, particularly for clays [17].

In addition, opacity, which is strongly influenced by factors such as void fraction and pigment alignment, is 3-4 points higher for curtain than blade coated papers. This difference in opacity can not be accounted to any one of the individual factors, void fraction or pigment alignment, but it is believed that lower opacity of the blade coated layer is due in part to higher alignment of clay pigments. Random orientation of clay pigments for the curtain-coated papers would lead to more random scattering and hence greater opacity. However, some misalignment will always occur with clay plates and GCC blocks, regardless of coating method.



(a) (b)

Figure 11: Statistical comparison of air permeability (PPS porosity) and opacity of blade and curtain coated paper (5.8 gm/m^2, C1S, Calendered 4 passes, 1500 PLI).

Figure 12 shows Root Mean Square (RMS) roughness of blade and curtain coated papers obtained from the AFM measurements a 10µ×10µ sample area. Again for the same coat weight, mean RMS roughness for curtain coated layer is 58 nm whereas it is 30 nm for blade coated layer. This is consistent with the PPS roughness values, although smaller by two orders of magnitude. This is consistent with previously reported results [18,19].

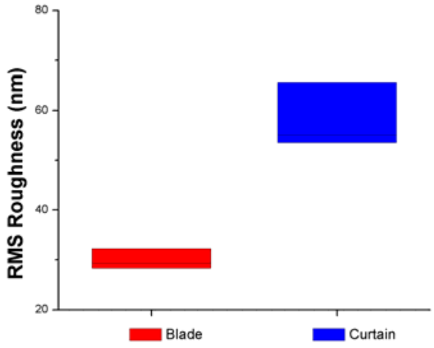


Figure 12: Root Mean Square (RMS) roughness of blade and curtain coated papers from AFM measurements in a 10μ×10μ sample area (in nanometers).

4.4 Comparison of Print Quality

The print density of the curtain coated paper was comparable to that of the blade coated paper, with the print density of the curtain coated paper being slightly higher. The mean print densities were 1.2 and 1.39 for blade coated and curtain coated papers, respectively. The print mottle was estimated using the Verity Print Mottle index [11]. The Verity index for the curtain coated paper is significantly higher than the blade coated paper, as seen in Figure 13. For the curtain coated papers, there was little or no effect of coat weight on print quality. Nevertheless, for the blade coated papers, print quality improved with coat weight.

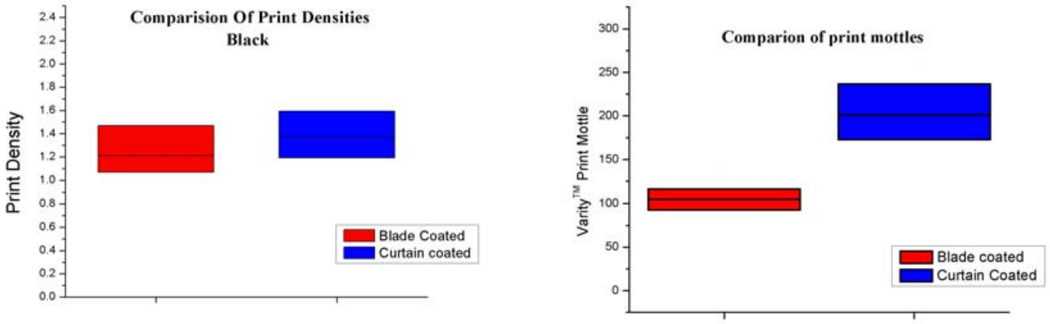


Figure 13: Comparison of printability of curtain and blade coated papers.

Smith [8] presented an explanation of the effect of basesheet –ink interactions on offset printability. High print densities are indicative of a higher thickness immobilized ink layer resulting from an open coating lattice and stronger base sheet and ink interaction. Due to the greater migration of the binder to the surface as a result of the more open coating lattice, the curtain coated papers received a thicker immobilized ink layer resulting in higher print densities.

Print mottle is a measure of ink film uniformity. Contour coated papers usually have higher print mottle [20] for offset printing, due to the incomplete contact of the paper with the ink film on the blanket, resulting in uneven ink transfer. This is consistent with the results of the current investigation. The curtain coated papers were significantly more mottled than the blade coated papers.

5 Conclusions

A curtain coater is a true contour coating operation. As a result, the surface properties differ significantly from blade coated (surface coated) papers. The scale of base sheet roughness dictates whether the wet film will follow the contour of the base paper or skim the surface, resulting in the formation of craters. The coating lattice of the curtain coated paper was determined to be much more open and the pigment alignment more random. The open coating lattice and random pigment alignment enabled more binder migration to occur during drying. The greater migration of binder during drying increased the concentration of the binder at the surface, resulting in higher print densities. However, the higher roughness of the paper resulted in a less uniform transfer of the ink, resulting in more print mottle. The near absence of shear during the curtain coating processes reduced the alignment of the pigment particles, which also increased the air permeability and increased the opacity.

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