The Trend towards Low Impact Coating of Paper and Board

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1. Abstract

Global production of coated paper for printing is currently about 45 - 50 million tonnes annually, with a predicted growth rate of between 3 and 4 %. In order to remain competitive, coated paper producers have had to increase productivity and reduce cost. One way this has been achieved is through developments in technology which make the papermaking, coating and finishing operations much more efficient.

Coated papers give much better printing quality than uncoated grades. The coating layer is made up of mineral particles (kaolin and calcium carbonate) with a latex binder, formulated above the *cpvc* so that the pores are filled with air. This controls the ink setting process and generates light scattering and gloss, important for the appearance of the sheet. The coating layer is typically about 10 to 20 µm thick on a basepaper of thickness between 50 and 100 µm.

In this paper we will illustrate some of the benefits to be obtained by reducing the physical impact of the coating application method on the basepaper. Starting from blade metering, the newer coating application methods including metered size press, spray and curtain coating will be compared.

Blade metering applies a large stress on the basepaper. This has the effects of forcing the coating into the pore structure of the paper and losing quality of coverage. Additionally, risks of breaks, with associated downtime, are high. Blade metering also has a speed limitation, with most machines limited to speeds slower than 1800 m min^{-1}.

The metered sizepress was developed in the 1980s and applies a premetered film of coating onto a backing roll followed by subsequent transfer to the paper. Both sides of the paper can be coated simultaneously. The impact on the basepaper is less than with blade metering, which gives improved coating holdout and allows cost reductions in the basepaper through the use of weaker fibre sources or higher filler levels. The runnability problems which limit the use of this equipment are film split patterns at low speeds and misting at high speeds. This limits the maximum speed to 2000 m min^{-1} at present.

Spray coating has recently been introduced to the paper industry. The process is very simple, with the coat weight and speed limited only by the number of spray nozzles fitted. Again both sides are coated at once, and quality is improved by arranging the nozzles so that the spray fans overlap. It is important to allow the drops time to spread on contact with the paper so that all the surface is covered. Hence the coating solids is low and rapid immobilisation of the drop should be avoided. Only one commercial spray coater installation has been made to date.

Curtain coating is currently being widely trialled by a number of suppliers. Already used in the coating of specialised papers such as carbonless copy grades, the higher quality required for graphic papers means that air bubbles must be reduced to a very low level. The advantages offered by curtain coating include very good fibre coverage resulting from the very low impact and the ability to apply multilayers simultaneously. This will enable the redesign of the coating to optimise both the optical and printing functions of the coating layer separately in a way not possible previously.

2. Introduction

Global coated paper production for printing amounts to between 45 and 50 million tonnes annually, with a growth rate of between 4 and 5%. Over the past 15 years there has been a downward trend in prices [1], and in order to remain competitive, mills have had to improve efficiency and reduce costs. A series of technical innovations have made a major contribution to this by improving process efficiency. Examples in the coating line include moving from roll to jet applicators, then to metered size press. These developments allow faster production speeds. Spray and curtain coating have progressed through the development stage and are awaiting commercial adoption. Other innovations include the streamlining of papermaking, coating and calendering into an continuous on-line process.

Paper coating formulations generally consist of a mineral or blend of minerals, and a binder / thickener combination. As the mineral pigment, kaolin (china clay) and ground or precipitated calcium carbonate are normally used, having a particle size substantially below 2 µm esd. The binder is normally a film-forming latex added at around 10 % by weight of the mineral. This is well above the *cpvc* of the system, so that the voids between the mineral particles are filled with air when the coating is dried. These pores are critical to the performance of the coating, generating light scattering (due to the RI difference between mineral and air) and controlling the rate of ink setting during printing, as a result of absorption of the vehicle. Useful introductions to the coating process can be found in references [2-4]. A micrograph of the coated paper surface is shown in Figure 1.

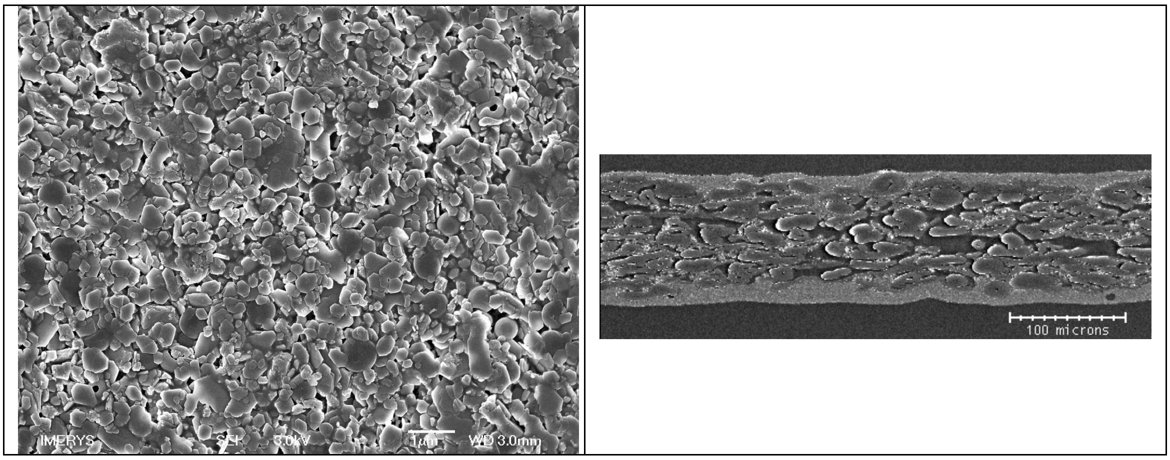

Figure 1. SEM of coated paper surface showing kaolin particles and pores (left) and cross section through coated sheet (right). Coating thickness is *ca*. 10µm.

In order to ensure that the development of coating pigments and binders keeps pace with the development of coating applicator systems, machinery suppliers carry out joint work with mineral and binder producers. Much of the work described in the next sections was carried out as part of this process. Some of the mineral developments are summarised elsewhere [5-7].

3.1. Blade metering

Historically, production of coated paper was carried out using air knife metering, which has a severe speed limitation (200 m min^{-1}). During the 1950s, metering using a steel blade was introduced and enabled paper to be coated at 600 m min^{-1}. The subsequent development of blade coaters during the following 2 decades tripled this speed to a maximum of 1800 m min^{-1}. The classical blade metering system consists of a roll applicator which initiates dewatering of the coating fomulation into the basepaper. The excess coating is then removed using a steel blade to give a controlled coat weight. Following drying, the process is then repeated on the other side of the paper. Such a system is referred as a long dwell, meaning that the wet coating is in contact with the paper for a relatively long time scale (of the order of tens of milliseconds) before metering. Later developments replaced the applicator roll with an applicator feed just before the blade, the so-called short dwell time system. Here the coating was only in contact with the paper for tens of microseconds. However, flow instabilities in the head gave problems with barring, and for the highest speeds with blade metering devices, current machines use a jet applicator, also a long dwell system.

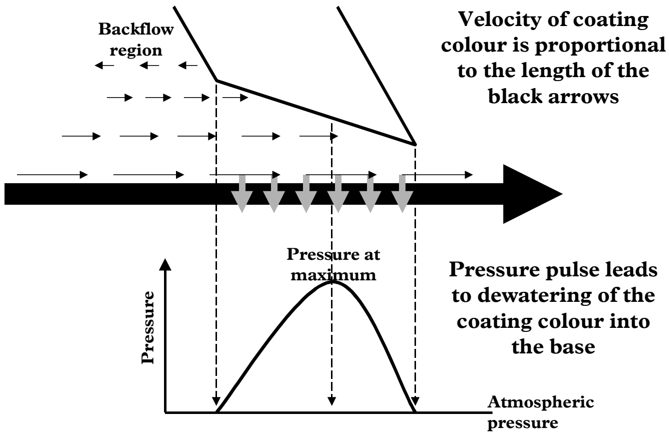

Figure 2. Diagrammatic representation of the pressure distribution under a metering blade.

All blade metering systems place a large stress on the paper, which increases with speed. The reason for this is shown in Figure 2, and arises from the loading applied to the back of the blade which balances the hydrodynamic force arising from the velocity of the coating. Kahila and Eklund have estimated that the pressure can be as high as 4 bar [8]. The stress is concentrated over a relatively small area under the tip of the blade, and frequently results in breaks during production, especially when coating lightweight papers at high speeds. The downtime associated with production breaks represents a major increase in cost for the papermaker. This is particularly the case where the papermaking, coating and finishing processes are all carried out in-line in a single operation, which is the most cost effective arrangement.

3.2. Metered size press

In the search for more efficient paper production, methods which placed less stress on the paper were needed. The most successful of these is undoubtedly the metered size press (MSP), or film, coater, introduced in the 1980s. This is essentially a development of the pond size press, which is a rather crude system normally used to apply a layer of starch solution to the paper.

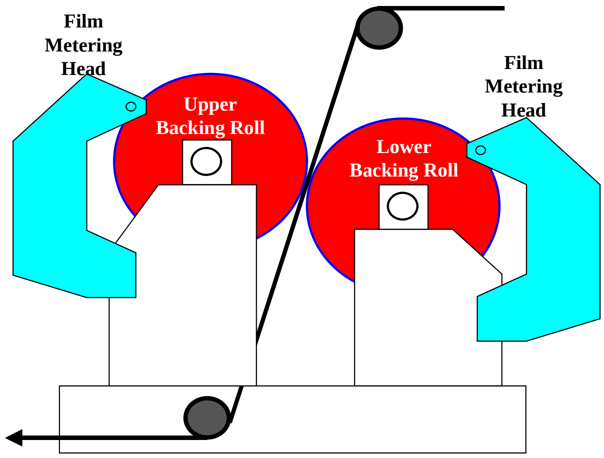

Figure 3. Layout of Metered Size Press

In the metering size press, the coating is premetered (using blades or rods) onto a pair of polymer covered rolls, which then transfer the coating to the paper. Both sides of the paper are thus coated simultaneously (Figure 3). For information on the development and use of the MSP the reader is referred to the proceedings of the four MSP Forums run by TAPPI between

1996 and 2002 [9-12]. The device puts less stress onto the paper than blade metering, which as well as reducing the number of breaks, has the benefit of giving improved coating coverage. Preston and Hiorns [13] showed that MSP coatings have a narrower distribution of coating thickness compared to blade coatings (Figure 4). A similar conclusion was reached by Endres and Tietz [14].

Installation of MSPs has accelerated the use of higher levels of mineral fillers and cheaper recycled fibre which further reduces the cost. The MSP is now universally chosen in new installations for the manufacture of lightweight coated (LWC) grades of paper, and there is interest in using MSPs to produce double coated grades as well.

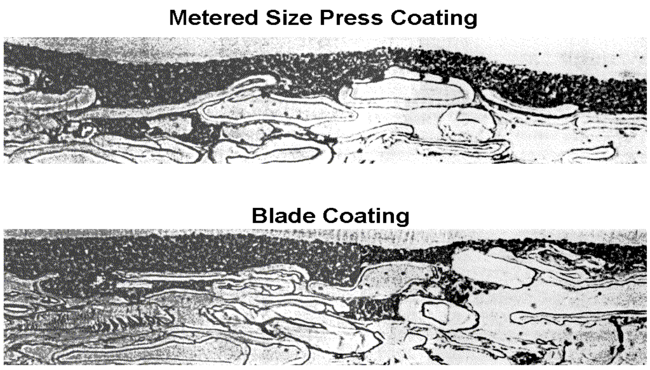

Figure 4. Cross sections of coated paper showing improved coverage with MSP.

The upper speed limit of the MSP is currently around 2000 m min^{-1}, and is constrained by the phenomenon of misting at the exit of the nip. This arises from filamentation during the film splitting process. A number of studies have been made to understand the phenomenon and propose a solution [15,16].

3.3. Spray coating

Spray coating has received considerable attention during the last few years. A commercial spray coating system for paper is available and there is currently one working installation in Europe. The spray coater is a simple system which can coat both sides of the paper at once. The speed and coat weight that can be applied is constrained only by the web handling system and the number of nozzles fitted. Coating quality is improved by arranging the nozzles in overlapping rows (Figure 5). Two banks of spray nozzles are fitted, so that one is in use while the other is being cleaned. The current life of each spray nozzle now extends to a period of weeks.

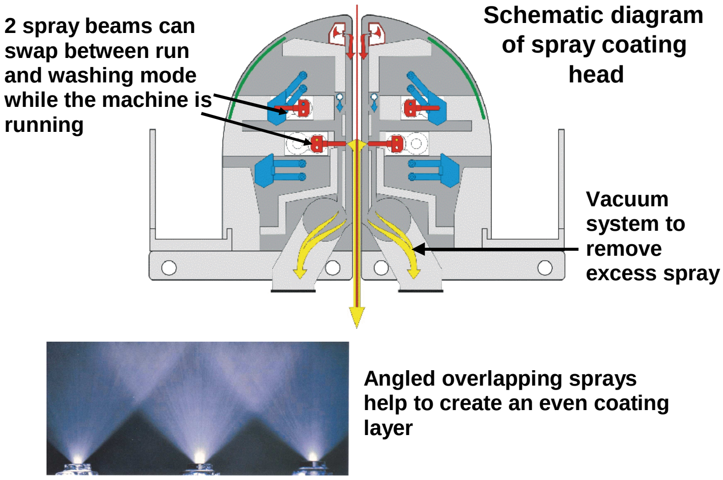

Figure 5. Spray coater layout (courtesy Metso)

The key to obtaining acceptable coating quality using a spray is to allow the droplets to spread and coalesce after they hit the paper. This is done by adjusting the basepaper properties and coating formulation so that the coating does not immobilise too quickly. Hence the basepaper water absorption should be low and the coating formulation water retention high, with a low surface tension. The coating colour solids is normally significantly lower than normally used : a recent study [17,18] suggests that spray coating at 55wt% solids gives similar paper properties to metered size press coatings applied at 8 units higher solids (Figure 6). This is a counter intuitive message to project to an industry where high coating solids traditionally equates with improved coating quality. It is likely, however, that due to high evaporation rates after atomisation, the droplet solids "on impact" is much higher than measured before spraying.

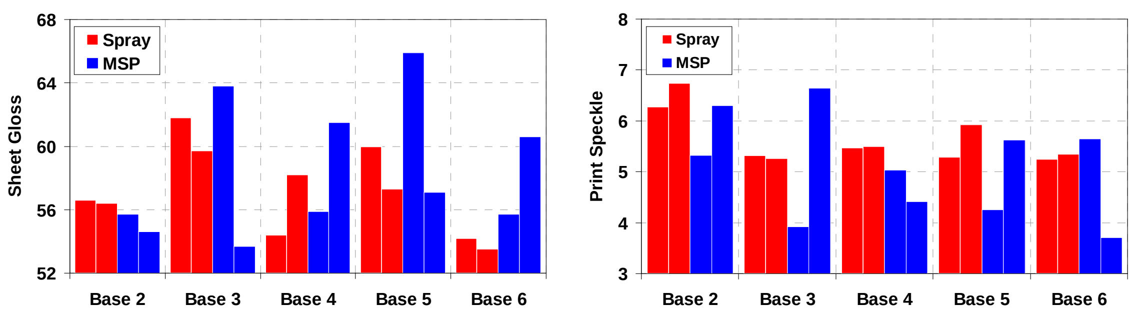

Figure 6. Pilot scale comparison of spray and MSP coating, showing sheet gloss (left) and print speckle (right) of LWC papers coated with a 70 carbonate / 30 clay formulation. Application solids were 55wt% for the spray and 63wt% for the MSP. 6 different basepapers were used. Higher numbers mean worse speckle. From ref.17.

If full coalescence of spray droplets is not attained, there will be small areas of uncoated paper which show up as white spots during printing at commercial speeds [17-19]. Laboratory printing is too slow and allows time for the ink to spread over the uncoated areas. This speckle detracts from the appearance of the print. Figures 7 and 8 show examples of this using a spray coated paper exhibiting incomplete coalescence of droplets :

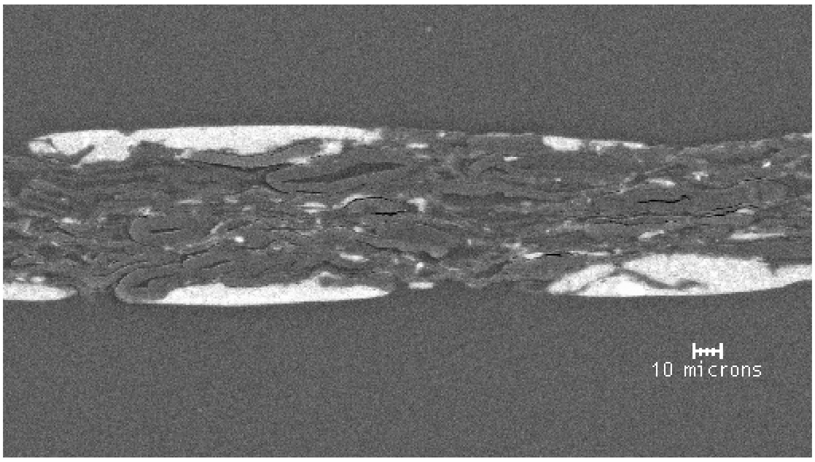

Figure 7. Cross section through a badly spray coated paper.

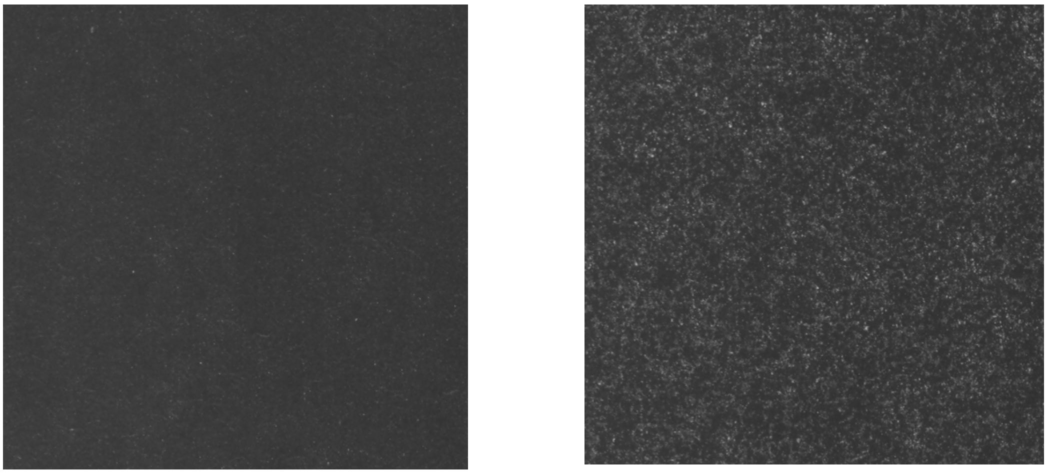

Figure 8. Commercial scale offset litho printing of blade coated paper (left) and badly spray coated paper (right) showing print speckle. 8 gm^{-2} coat weight, 100% black area.

3.4. Curtain coating

Considerable research effort is currently being spent to apply the technique of curtain coating to graphic papers. Already used in less demanding speciality grades like thermal papers, its use in high quality graphic papers requires extremely low levels of air bubbles. Producing a stable curtain across a 9 m wide web will also be a challenge. Some publications have already been made which establish the operating parameters for high speed curtain coating of graphic papers at pilot scale. Triantafillopoulos *et al*. [20] describe trials in which successful curtain coating of paper webs was achieved at speeds of 1400 m min^{-1}. Coating coverage was superior to MSP coated control papers. Other studies published recently describe the influence of parameters such as dynamic surface tension [21,23] and elongational viscosity [22,23].

The most promising application currently is in the coating of paperboard, particularly when the substrate is dark in colour. Slow speed air knife coaters are often used to give a contour coat of opacifying mineral in order to cover the dark base. The curtain coater has been shown to provide a similar contour coating, but at higher speeds, which minimises brightness mottle in the final coated board. A joint study has recently been published [24] which shows that while the contour nature of the coating gives an even appearance, it gives a coating with a high roughness and low gloss (Figures 9 and 10). The high roughness leads to very poor print quality when the board is printed by the rotogravure process (Figure 11). A combination of curtain and blade seems to best compromise to obtain even appearance and acceptable smoothness.

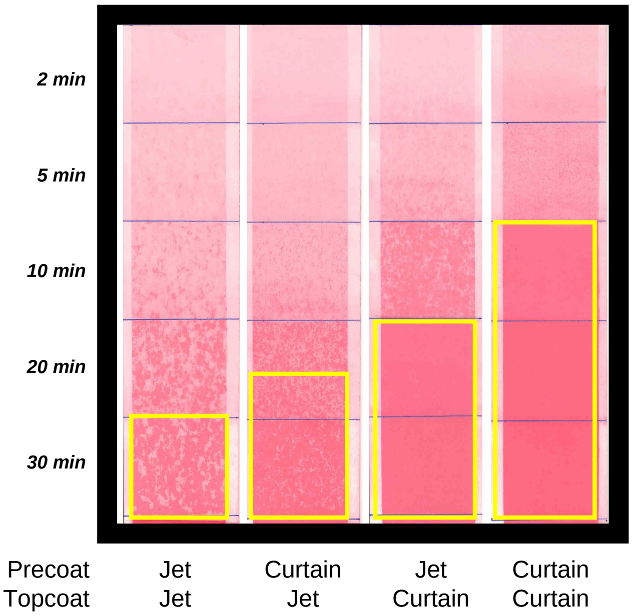

Figure 9. Red wipe test showing uneven absorption of ink by blade (jet) coated board. Appearance is much improved using curtain application in one or both layers (from ref 24).

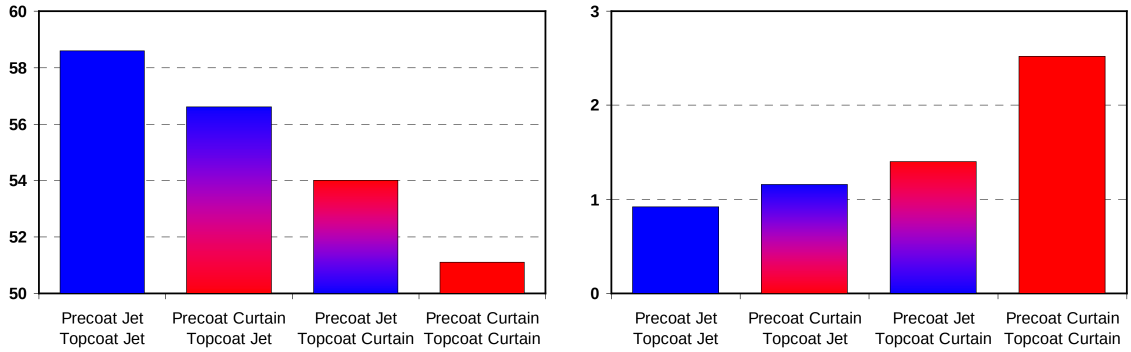

Figure 10. Double coating of board comparing curtain (red) and jet/blade (blue) application. Left gloss (TAPPI 75°), right roughness (Parker Print Surf, 1000 kPa, µm. Higher values mean rougher surface). (From ref. 24).

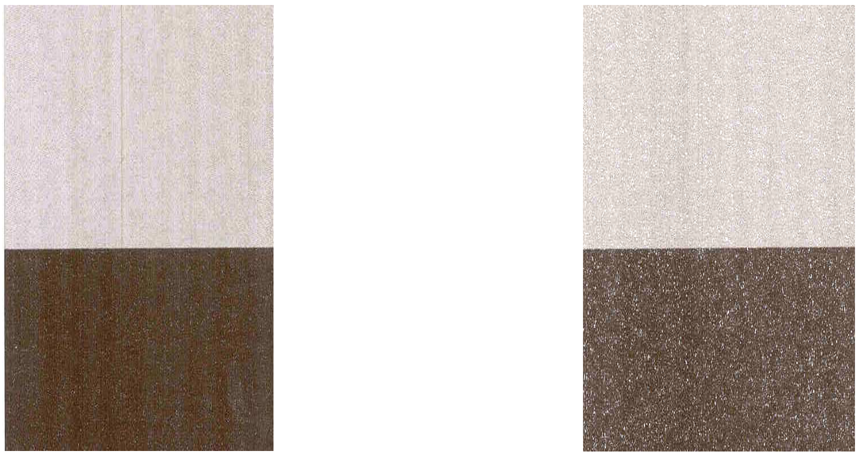

Figure 11. Coated boards printed by rotogravure. Left, blade on blade, right, curtain on curtain. Much higher level of print speckle (unprinted dots) with curtain coated sample due to rougher surface.

A second advantage of curtain coating lies in the potential to apply several layers simultaneously. Thus future coater designs could have a much smaller footprint, but more exciting is the potential to functionalise each layer. Hence the light scattering and ink accepting functions of the coating could be decoupled, allowing the sheet to be redesigned. Other functions, such as a barrier layer, could be introduced. Such concepts were illustrated recently in two papers presented at the TAPPI Coating Conference 2005. Urscheler *et al*. [25] describe trials in which up to 3 layers were applied simultaneously. They also demonstrated the concept of an "carrier" or interface layer to assist the wetting of the substrate. Top layer coat weights as low as 2 gm^{-2} were shown to be effective in conferring gloss and printability. Hiorns and Kent [26] showed that applying multiple thin (~2 gm^{-2}) alternating layers of kaolin and precipitated calcium carbonate (PCC) gave synergistic increases in light scatter and gloss compared to using thick layers of each or simple blends of the two minerals (Figures 12 - 13). This is a result of the higher porosity and hence air content of the PCC layers compared to the kaolin, which generates alternating layers having different refractive indices - the minerals themselves have very similar RI values. Using thinner layers increases the number of refractive index steps and brings the size of each scattering layer closer to the wavelength of light. Similar effects could be achieved using minerals of higher RI such as TiO_2 but at much higher cost. Although Hiorns and Kent used wirewound rods and very dilute coating colours in the laboratory, using a multilayer die on a curtain coater is currently the only way of realising such a structure commercially.

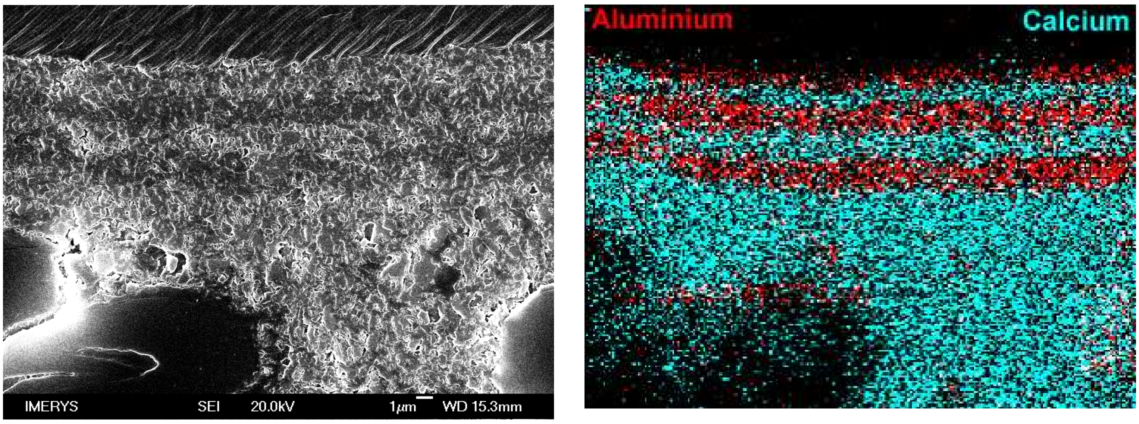

Figure 12. Left, SEM of cross section through multilayer coated paper.
Right, EDX mapping of of the same section showing alternating thin layers of kaolin (Al signal) and calcium carbonate (Ca signal). From ref 26.

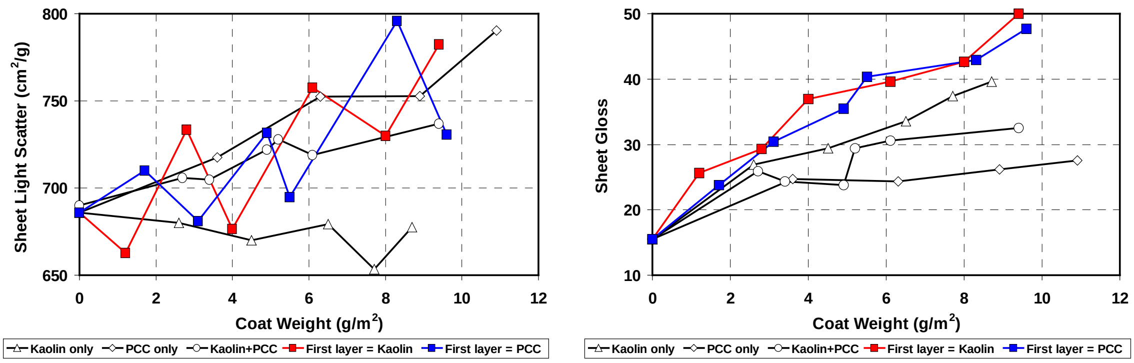

Figure 13. Properties of multilayer coated paper, left, light scatter, right, gloss. Showing benefits of alternating thin layers compared to coatings of single components and simple blends. From ref. 26.

3.5. Dry coating

Still in the early stages of development, the concept of applying the coating in powder form electrostatically, and then thermally plasticising the coating layer has been developed in the laboratory [27]. Based on the principles of xerography, this work has shown that, using conventional coating formulations and ingredients which have been freeze-dried, coating properties which are comparable to those of conventional papers can be obtained, although the binder level required is at least double. The average pore size is also larger than in conventional coated papers. However, there is much development still to be done, and it is unlikely that conventional film forming latexes and coating pigments will be optimised for this technology. Such a process removes the drawbacks associated with wetting and swelling of the fibres, but replacement of conventional coating processes would require huge volumes of very low density powder to be manufactured and transported. In our view, the process is most likely to be used as an “add-on” to a printing line to upgrade relatively small volumes of bespoke product.

4. Conclusions

During the past 25 years, there has been an intensive period of innovation which has resulted in a number of new ways of applying coatings to paper substrates while reducing the stress placed on the sheet. This has made the manufacture of coated paper more cost effective in several ways –

- Reducing the footprint of the coating unit and dryers through simultaneous 2-side coating of the paper web,
- Increasing the speed of coaters compared to conventional blade metering technology,
- Replacing more expensive virgin fibre with cheaper recycled fibres and mineral fillers,
- Reducing the number of breaks and aligning the paper production process so that all the operations, paper making, coating and finishing (calendering) are carried out in-line,
- Improving the quality of coverage so that improved paper properties can be offered, or coat weights reduced for the same properties. Lower impact coating techniques have facilitated the use of higher levels of brighter calcium carbonate, which with blade metering gives more penetration of the coating into the basesheet than plate-shaped kaolin particles.

At the present stage of development, the most potential for developing new and innovative coating structures is offered by the multi-layer curtain process, where thinner layers with individual functions could lead to redesign of the coated sheet.

5. Acknowledgements

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