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Producing different surface structures for LWC matt paper for CSWO printing

LWC matt paper grades for coldset web offset offer the biggest quality achievement potential since the introduction of 4-colour printing in CSWO printing industry. But, to fully benefit from the business potential of Matt LWC grades, a lot of work is required in various areas.

- *optimisation of production lines*
- *optimisation of sheet quality*
- *optimisation of printing process*
- *optimization of the end-use concept.*

This article deals with the first two areas: production technology and the quality of the product.

Commercial base papers, produced with different technology and raw materials, are coated in pilot conditions and then printed in commercial conditions. Confocal Raman technology is used to identify the binder concentration in both lateral and z-direction of the coated paper samples; and, the ink pigment compounds in the paper surface.

The analyses show i) that base paper structure has influence on the composition of the coating structure, when using the metering size press; ii) that latex coverage of the paper surface has influence on the build-up tendency of LWC matt papers in satellite type CSWO printing press; iii) evidence that ink pigments used in CSWO printing do penetrate through the whole coating layer all the way to the base sheet surface.

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Matt LWC paper grades offer the biggest quality achievement potential since the introduction of 4-colour printing in CSWO printing industry. In order to fully benefit from the business potential of Matt LWC paper grades, a lot of work is required in various areas; optimisation of production lines of these paper grades, optimisation of quality of the sheet for CSWO printing, optimiszation of printing process to print coated grades and optimisation of the end-use concept.

This presentation deals with the first two areas: optimisation of production technology and optimisation of the quality of the product.

In order to create the basis for the business concept of Matt LWC CSWO grades, state-of-the-art production technology is necessary. Two years of experience with on-line coating and calendaring in the speed range over 1400 m/min has shown that variations in the operation are not tolerated. Stable quality of base paper and coating colour are essential in order to achieve good performance.

The key success factor for the Matt LWC paper grades is to define what the optimised printing surface is and how this can be produced with chosen production technology. In order to characterise the potential printability of Matt LWC paper grade new analysing techniques – e.g. ink paper interaction, absorption properties etc. – have been developed[1].

Coating structure plays a major role in the surface structure of Matt LWC grades, a fact which can be proved by applying existing analysing techniques (Raman, Emco).

In the following paragraphs, this article goes through the definition of optimised printing surface of CSWO Matt LWC papers, introduces the main elements of the production technology for Matt LWC paper grades, characterises Matt LWC paper surface with Raman technology, and finally, presents the main findings about optimal printing surface of CSWO Matt LWC papers.

Optimised Printing Surface of Matt LWC Grades

The main objectives defining the optimal printing surface of Matt LWC paper grades are print quality and runnability on a CSWO printing machine. As *Figure 1* illustrates, the main attributes contributing to CSWO print quality are colour reproducibility (colour gamut),

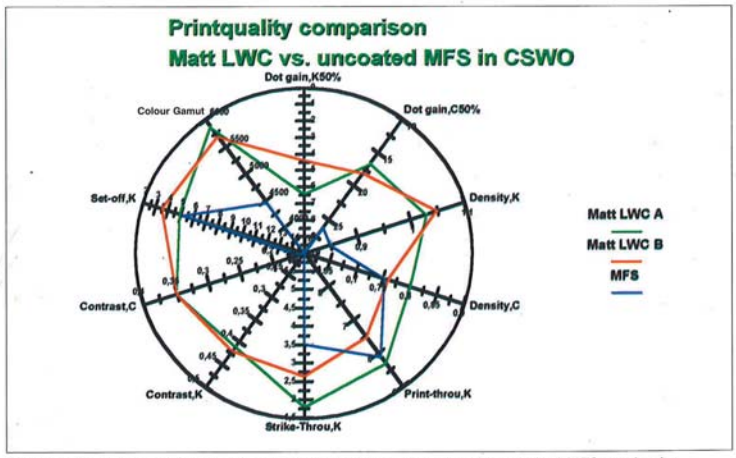


Figure 1: Print quality comparison between Matt LWC grades and uncoated MFS grades in CSWO. The bigger the surface the better the relative print quality.

dot-gain, set-off, contrast, print- and strike throw at a given density.

Figure 1 shows that better overall print quality can be achieved when using Matt LWC grades in CSWO compared to uncoated grades (MFS).

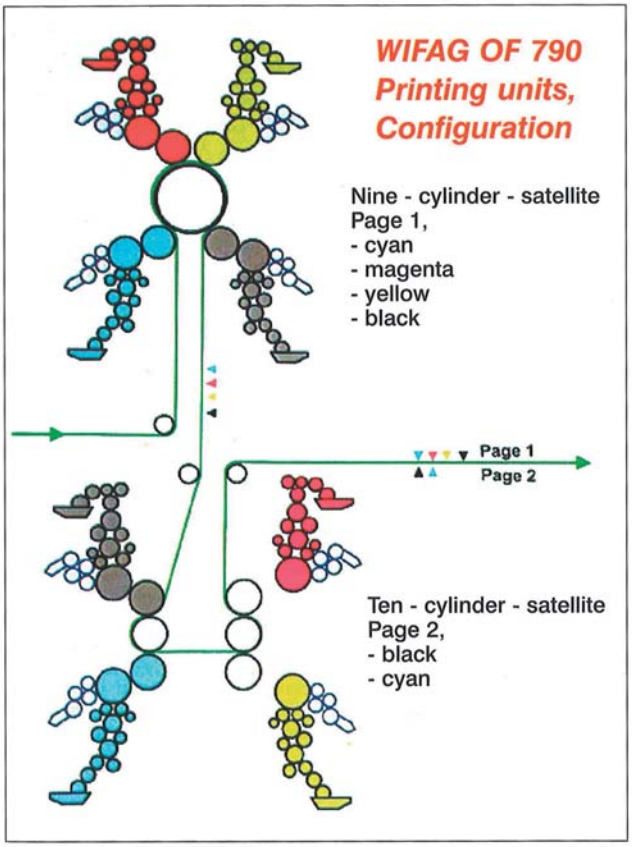


Figure 2: Schematic of satellite CSWO printing machine. Arrow is pointing to the second CIC, where the deposits are forming

The major contributing factors to print quality of Matt LWC grades are: coating coverage, physico-chemical structure of coating layer and compressibility of the sheet. An optimised printing surface is achieved through high and even coating coverage, which creates maximum absorption capacity/porosity and is highly permeable.[1] In addition the pigment particles in the coating need to be sufficiently well bound to the base paper's fibre matrix.

On the runnability side, the main factors include: a low web-break rate and low build-up tendency on blankets and cylinder surfaces resulting in long washing intervals. *Table 1* summarises the factors influencing the optimal printing surface of Matt LWC grades in CSWO.

This paper concentrates on investigating the influence of base sheet properties on final coating structure, Raman technology being used as a tool to define the coating structure. The influence of base paper and coating structures on CSWO printing press runnability are also investigated.

Two hypotheses were created in order to characterise the relationship between base sheet structure, coating structure and CSWO printing press runnability:

1. Base paper structure influences the coating layer formation when metering size press coating is used for the production of LWC Matt paper grades for CSWO printing.
2. Binder distribution (lateral or z-direction) in the coating layer of LWC Matt paper has an influence on ink build-up tendency on the second impression cylinder of CSWO satellite press configurations.

Since practical experience has shown that the runnability of Matt LWC papers in CSWO printing is excellent in blanket-to-blanket configurations, the runnability problems are more precisely defined as the build-up tendency on the metal surface of the common impression cylinder of satellite type press configurations, as *Figure 2* illustrates[1].

Optimised Printing Surface of Matt LWC (CSWO)

• High coating coverage	→ base sheet properties, coating colour properties, application technology
• Even coating coverage	→ base sheet properties, coating colour properties, application technology
• Good absorption capacity	→ coating structure, base sheet properties, coating application technology, finishing technology
• High permeability	→ base sheet properties, coating structure, coating application technology, finishing technology
• Good bonding of coating to base	→ Base sheet structure, application technology

Table 1: Definition of optimised printing surface of Matt LWC grades for CSWO and description of the influential operational parameters

Experimental

At the experimental stage, base sheets produced on two different commercial production lines were coated with different coating colours in pilot conditions. The coated papers were calendared in pilot conditions to a constant roughness level and then analysed and printed on a commercial CSWO printing machine.[2]

Base papers: UPM Matt is currently produced on two production lines, both of which are equipped with an Optipress type press section. The base papers used in this study are taken from these two production lines.

At mill A, fibre raw material consists of mechanical pulp; at the mill B fibre raw material is a mixture of mechanical, chemical and recycled fibre.

Two modified base sheets were obtained from mill A – by changing the type of filler used in the base sheet and by modifying the press section.

Base A2 was produced with optipress consisting of the following press section:

1. First nip: a grooved/suction roll type of nip
   Second nip: a shoe-press type of nip.

Base A3 was produced with optipress configuration consisting of following press section:

2. First nip: Grooved/grooved roll type nip.
   Second nip: a shoe-press type nip

Altogether the main variables of base papers are: fibre raw material; filler type and content and the effect of press section modification on water removal and base paper structure. *Table 2* summarises the different base papers used in this study.

Pilot coating: These base papers were coated in Järvenpää on Metso paper's pilot coater. The layout of the pilot coater is shown in *Figure 3.*

The coating colour was applied onto the roll surface with a smooth rod. The targeted coat weight was 6 g/m² per side. Rod diameters varied between 12-25 mm during the coating trial.

On the OptiSizer, the nip linear load was constant at 20 kN/m during the whole trial, and roll hardness was 35 P&J. The speed of the coating unit was constant at 1500 m/min during the whole trial. Turn-dry and IR dryers were used to dry the coating as can be seen from the schema in *Figure 3.*

In pilot conditions, the temperature of the base paper differs from the value at the on-line coating units. On commercial production lines, web temperatures can be around 50-70 °C when entering the coating unit. In pilot coating, the temperature of the web was 18-23°C and it was determined by a laser thermometer during the trial.

Coating colours: The pilot coating trial was carried out with two different coating colours. All four different base papers were coated with coating colour 2 and colour 1 was used in combination with base sheets A3 and B. In both coating colour recipes, the main coating colour pigment was calcium carbonate. The main differences between two colours were:

a) different type of pigment
b) different latex type
c) different latex content
d) different additives

A1	**Mill A base paper before the press section modification, carbonate as a filler and mechanical pulp as fibre raw material**
A2	**Mill A base paper before the press section modification, clay as a filler and mechanical pulp as fibre raw material**
A3	**Mill A base paper after the press section modification, clay as a filler and mechanical pulp as fibre raw material**
B	**Mill B base paper, mechanical and chemical pulp and recycled fibre as raw material**

The grammage of base paper A is 45 g/m² and the grammage of the base paper B is 50 g/m².

Table 2: Different base papers from commercial production lines used in this study

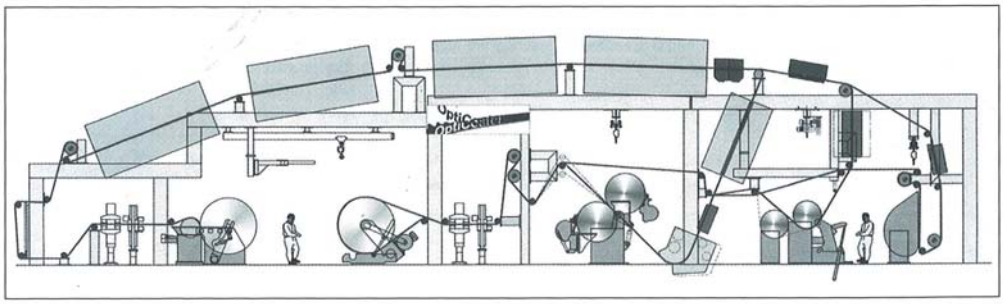


Figure 3: Optisizer, (Metered size press coater), Metso Corporation. Coating mode used C2S, i.e. coating colour is applied to both sides simultaneously[3]

The coating colour compositions can be seen in *Table 3*. The targeted pH was 8,5 and the targeted solids content was 64%.

The particle sizes of two main coating colour components, calcium carbonate and styrene-butadiene latex are shown in *Table 4*. Calcium carbonate A has narrower particle size distribution than calcium carbonate B. Particle size distributions are obtained from the suppliers of raw materials.

Commercial printing tests: Pilot coated and calendared papers were printed at a Central European CSWO printing press. The press was a WIFAG OF 790 satellite coldset offset press, as the schematic drawing in *Figure 2* shows. All papers were printed in stable conditions using same process chemicals.

Press runnability was evaluated in terms of the deposit build-up tendency on the first common impression cylinder (CIC) of the second satellite unit and on the blankets. After approximately 30,000 cylinder revolutions, the press was stopped and the common impression cylinder was inspected and digitally photographed. The images were analysed visually and the build-up tendency was evaluated using a 1-9 scale, where 1 is worst build-up and 9 is clean cylinder or blanket.

Measurements

Absorptivity and some paper technological measurements were performed on the base papers and final products. Raman analyses were carried out on coated papers and partially on printed surfaces as well.

Absorptivity analyses: The absorptivity of all test papers, base and final product, were investigated. Water absorption, Unger oil absorption and K&I ink absorption, dynamic penetration of liquids were investigated with an CSWO dynamic penetration method.[2]

Microscopy: Both base paper and final products were measured. Coating structures, i.e. in lateral and vertical directions, were imaged using a scanning electron microscope at the UPM-Kymmene Research centre in Valkeakoski. The SEM-BSE method was used for coating coverage and SEM-EDS for filler distribution quantification. The SEM-BSE measurement was carried out for all coated paper samples and filler distribution. SEM-EDS was applied to all base papers.[2]

Confocal Raman microscopy: Confocal Raman measurements were carried out at Helsinki University of Technology. Raman spectra of the samples were collected with a dispersive Kaiser optical Systems HoloLab 785 Raman microscope.

In this kind of microscope the exiting light from a 785 nm diode laser is directed into the microscope through an optical fibre, which acts as a confocal pinhole rejecting signals from out-of-focus zones.

The depth resolution of the microscope of the Laboratory of Forest Products Chemistry at HUT was 5 µm and the lateral resolution was 2.5 µm. Spectra of model compounds and coating surface maps in lateral direction were measured with a metallurgical 10X objective. All the depth profile experiments were carried out with 100X oil-immersion objective.[2]

Movement of the focal point in the vertical direction was accomplished with a Physik Instrumente' PIFOC® piezo objective scanner. The scanning range of the equipment is 100 µm and full range repeatability is ±20 nm. In the lateral direction, the sample stage was controlled with a Coherent EncoderDriver™ actuator system with 0.1 µm repeatability. In addition, the spectrometer was connected to Olympus Bx60 microscope.[2]

Raman spectra were measured with a Holograms programme. The raw data was further analysed with GRAMS and Matlab programmes. Coating and ink layer thicknesses were calculated using the knowledge of the instrument's response curve[4].

The top and bottom sides of three base paper samples and eight coated paper samples were measured. In addition, depth profiles of four printed samples were measured from one side. Surface maps of two coated samples were measured.

Raman bands of the following model compounds were measured in order to identify the characteristic bands of each component in Raman spectra:

- Calcium carbonate
- Styrene –butadiene latex
- PVA
- Starch
- Hardener
- Magenta ink

Component	Colour 1	Colour 2	ppw
Calcium Carbonate	B	A	
S B-latex	B	A	5-10
Additive 1	B	–	
Additive 2	B	A	
Additive 3	B	A	
OBA	B	B	

Table 3: Coating colour compositions. A and B are used to describe the type of raw material.

Component	Particle size or size distribution
$CaCO_3$	
A	79% < 2µm
B	70% < 2µm
SB-latex	
A	0.14µm
A	0.14µm

Table 4: Particle size / size distribution of two main coating colour components, calcium carbonate and styrene-butadiene latex.[2]

All the paper samples used for depth profiling were pre-treated with a refractive index matching liquid in order to reduce disturbing light scattering in the sample. The pre-treatment liquid used in the experiments was silicon oil. In addition to silicon oil, immersion oil was used at the experimental set-up[2].

The immersion oil has a strong Raman band at the same wave lengths as the samples. Therefore it is necessary to use silicon oil as an other immersion fluid. The Raman band of silicon oil is usually at different wave lengths from the Raman bands of the sample[5].

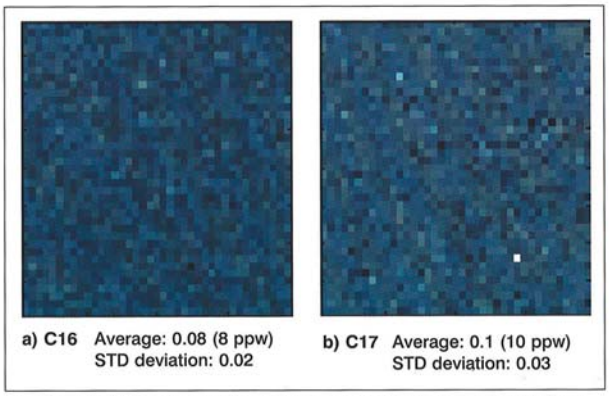
The depth profiles of the coating layer were collected by focusing the exiting laser beam stepwise into a sample. A separate Raman spectrum was collected at each step. The collection time for a Raman spectrum was from 10 s to 15 s depending on the paper sample. The depth of one step in the vertical direction (i.e. z-direction) was 1 µm while the total depth of the measurement was 40 µm. Two parallel samples were chosen from each coated test point and 6 parallel depth profiles were measured from each test point.

Raman maps in the x-y-plane were measured from two points in order to study the pigment and binder distribution on the coating surface. The size of the measurement area was 3.9 mm x 3.9 mm. The Raman spectrum was collected by focusing the laser beam stepwise on the coating surface. The length of a step was 100 µm.[2]

The Raman spectra of printed samples where measured from 100 % density areas of magenta ink from the printed test formats. The measurements were carried out with two parallel samples / test point. Each test point consisted of 12 parallel depth profiles[2].

Trial point/Build-up index	Build-up index		
Base A1+CC2 (C17) Base A3+CC1 (C15)			9 9
Base A3+CC2 (C19)		8	
Base B +CC1 (C16) and CC2 (C20) Base A2+ CC2 (C18)	6 6		

Table 5: Results of visual evaluation of runnability of the trial papers on a commercial CSWO printing machine. Difference from 6 to 9 is significant



a) C16 Average: 0.08 (8 ppw) STD deviation: 0.02

b) C17 Average: 0.1 (10 ppw) STD deviation: 0.03

Figure 4: Confocal Raman surface maps[2] in lateral direction. Trial papers: base B+coating colour 1(C16) in left side and base A1+coating colour 2 (C17) in right side. SB latex 'coverage' (SB latex-$CaCO_3$ ratio) is illustrated with grey shades. The 'dark spots' represent areas, where latex coverage is almost completely missing.

Results and Discussion

Binder distribution: During the commercial test printing of these trial papers, significant differences in the build-up tendency were noticed. *Table 5* shows the results of the runnability analyses.

Figure 4 illustrates that the lateral binder distribution on the surface of trial papers differs between papers which did and did not perform well, C17 and C16, respectively.

Paper with a lower build-up tendency has a higher SB latex content in the surface layer. As *figure 5* illustrates, the latex content in the surface of the sample can be described as kind

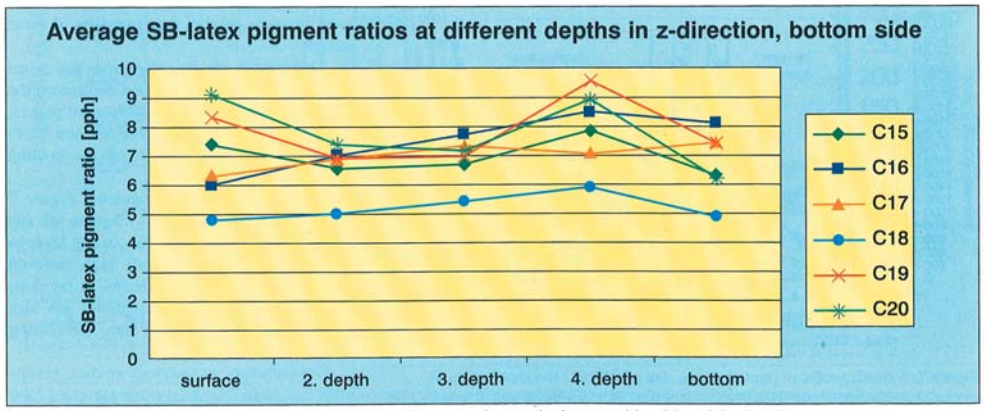


Figure 5: Average SB-latex pigment ratios on the bottom side of the trial points[2]

of 'latex coverage'. This latex coverage seems to have good correlation with the CIC surface build-up tendency of the paper.

It can be clearly concluded from results of lateral analyses of the samples shown in *figure 4*, that if the SB latex coverage of the first surface layer is too low, the paper has a high build-up tendency at CIC surface.

It can be also concluded, that a minimum concentration of SB latex is needed in the whole depth of coating layer of the paper in order to minimise the build-up tendency. This is illustrated in *figure 5*, where it can be seen that C18 has the lowest SB latex content of all the trial papers – throughout the whole depth profile measured – and a high build-up tendency at the CIC surface.

When this minimum concentration is exceeded, other factors, like latex coverage of the surface, permeability of the sheet, compressibility and high absorption capacity/porosity are becoming dominating factors[1]. This is illustrated in *figure 5*, where it can be seen that trial papers C16 and C17 have very similar SB latex concentration depth profiles (z-direction) yet very different build-up tendencies.

It is interesting to notice that differences in binder contents in the depth profiles can not be distinguished between coated samples – although it is known that SB-latex content in the coating colour recipes 1 and 2 are different.

It also seems that SB-latex content is relatively constant throughout a depth profile (z-direction) although binder contents seem to differentiate from one parallel measurement to another within the same sample. It can be concluded that these measurements, illustrated in *figure 5*, show very small signs of binder migration phenomena.

Confocal Raman surface maps provide information from a relatively large area: i.e. 3.9 x 3.9 mm, whereas the depth profiles are done in a small area, 2,5 µm in lateral direction.

As *figure 6* shows, the coating coverage – calculated from SEM images in these trial papers obtained by the metered size press application, can be as low as 57%.

Due to low coating coverage, it was difficult to find areas where several measurements could have been carried out beside each other. Therefore it was decided to do depth profile measurements from areas where the intensity of calcium carbonate was relatively high – an indication that the coating layer thickness was also adequate. In other words, suitable measurement points had to be chosen subjectively, and still the variation was dominant between parallel depth profiles of same sample.

Therefore it can be concluded, that when studying the effect of SB latex content on the build-up tendency of these LWC matt papers, the surface maps provide more relevant information than depth profiles of the coating layers.

Position of magenta pigment: *Figure 7* shows one example of how magenta ink sits on the surface and inside the coating layer in paper which has a relatively high build-up tendency. It has been suggested in previous studies that ink pigment particles are size excluded from penetrating into the coating layer[6].

Contradictory to previous studies, results obtained from Raman measurements of LWC matt papers printed on commercial CSWO

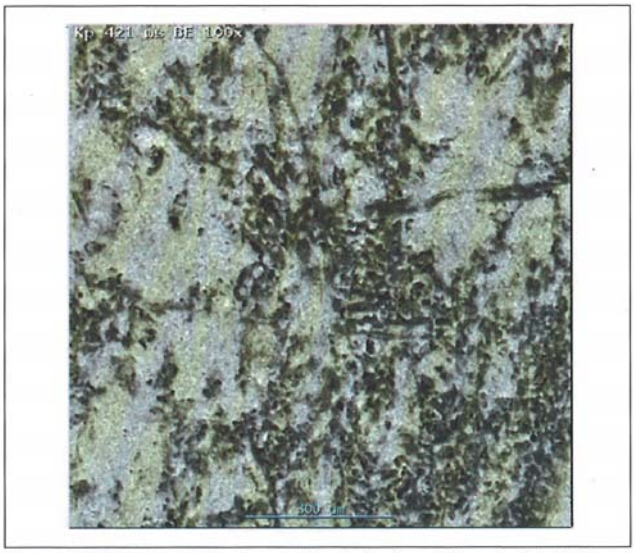


Figure 6: SEM backscattering images of coated surfaces of sample C17. Bottom side of the sample with an average coating coverage of 57.1 %.[2]

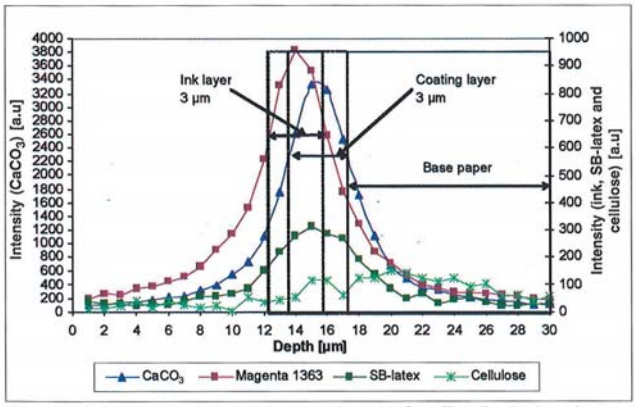


Figure 7: A depth profile of printed paper, trial point C18. The distribution of magenta ink, coating colour components and cellulose is shown by step response curves.[2]

printing machine show that i) in some cases, ink pigments were completely inside the coating layer; and ii) sometimes ink has penetrated all the way through the coating layer to the base paper. It seems that, on average, most of the magenta ink pigments are located inside the coating. An example of this can be seen in *figure 8*.

Base paper structures: Based on the results from the base papers used in this study, it can be said that base papers differed from each others.[2]

However, the main differences in base paper properties seems to be due to different fibre raw materials. Base papers of set B differed from the base paper of sets A1-A3. Most notable were the differences in Bendtsen porosity and dynamic water penetration.

Base paper with carbonate as the main filler had different structural properties than base paper sets with clay as the main filler. The main indicator for this was the porosity which was lower with clay as the main filler.

Measurement	Unit	A1	A2	A3	B
Grammage	g/m²	45.3±0.1	44.8±0	45.4±0.2	50.0±0.2
Thickness	µm	81.5±0.7	76.0±1.0	77.8±1.0	86.4±2.1
$Porosity_{Bendtsen}$	ml/min	305±21	157±6	183±8	316±24
$Filler\ content_{total}$	%	9±0.1	10±0.1	12±0.1	16±0.3

Table 6: Structural properties of base papers. Results are given as average values with standard deviation.[2]

The influence of wet pressing modification on base paper properties is marginal. Neither porosity nor roughness seemed to be altered as a result of the nip modification. No changes were detected in absorption values either.

Base paper and coating structures: In order to identify the role of base paper variables in binder distribution (depth or lateral) of the trial papers, an investigation was focused on the question – "can the lower latex content in the depth profile of trial paper C18 be explained by base paper variable(s)?"

The only difference, which could be found compared to other base papers, is the Bendtsen porosity of C18 (base A2) base paper, as *table 6* shows. It is thought that this is also a difference in formation, which was not measured in this study.

It can be concluded, that the physical structure of base paper seems to have contributed to the absolute latex concentration in the Z direction of samples coated in this experiment. The mechanism is not fully understood and further investigations are needed.

A second analysis was performed in order to find if base paper variables could explain why the standard deviation of the latex content (latex coverage) in the lateral measurement of trial paper C17 (base A1) was 30% higher than that of trial paper C16 (base B).

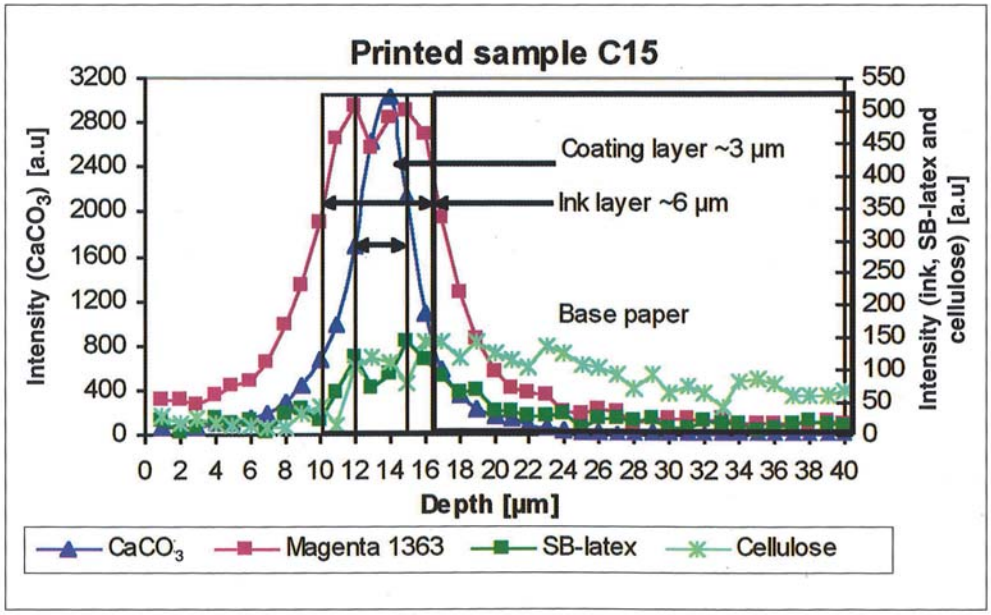


Figure 8: A depth profile of printed paper, trial point C15. The distribution of magenta ink, coating colour components and cellulose is shown by step response curve.[2]

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It can be concluded that there are major differences between base B and base A1 as *table 6 and figure 9* show. Base B has clearly the highest water absorption rate and the highest Bendtsen porosity. This can be mainly explained, among the variables studied in this experiment, by higher filler content, different raw material and different forming section.

The contribution of different formation was not studied in this experiment, although it is thought to have an influence on the 'evenness' of latex coverage of the surface. It can be concluded that the role of base paper formation in the evenness of latex cover of the surface requires further investigations.

It can also be concluded that the base paper structure does influence both the absolute binder concentration at the paper surface depth profile (z-direction) and the uniformity of lateral latex coverage of the surface. The main contributing factors to the base paper structure were identified as: raw materials-: fibres, fillers, fines and additives; and process variables – forming section, fabrics, short circulation, etc.

Conclusions: influence of base paper structure

It can be concluded that base paper structure at least partially influences coating layer formation when coating LWC matt paper grades with film coating technology. More precisely, it can be concluded, that the base paper structure does influence i) the absolute level of binder concentration in the coating layer (z-direction) and ii) the uniformity of lateral latex coverage of the surface (x-y direction). This proves the first hypothesis correct; the base sheet influences the coating layer formation in metering size press coating application.

The main contributing factors to the base paper structure were identified as: raw material mixture, forming section and process variables and filler content. The conceptional variables in the press section had marginal influence on the physical structure of the base sheet.

No evidence was found that the base paper absorption properties and the distribution profile of latex in the z-direction of the coating layer have a correlation to base paper structure.

It can be concluded that the second hypothesis – on the correlation of binder distribution to CIC build-up tendency – is proven to be correct with the qualification that both, the absolute binder content in Z-direction of the coating layer and the average concentration in lateral distribution of binder need to be above a certain, critical level.

When the minimum z-direction concentration is exceeded, other factors, like latex coverage of the surface, permeability of the sheet, compressibility and high absorption capacity/porosity become dominating factors[1] for the CIC build-up tendency.

It is concluded that lateral latex coverage – especially the areas, where latex is missing – increases the CIC build-up tendency on satellite type CSWO printing machines. Future investigations are needed to create a mathematical model of the latex coverage that correlates with the CIC build-up tendency.

It was found, contradictory to some earlier studies[6], that in CSWO printing magenta ink pigments do penetrate through the coating layer all the way to the base sheet.

It can be concluded, that when studying the effect of SB latex content on the build-up tendency of these LWC matt papers, the surface maps provide more relevant information than depth profiles of the coating layers.

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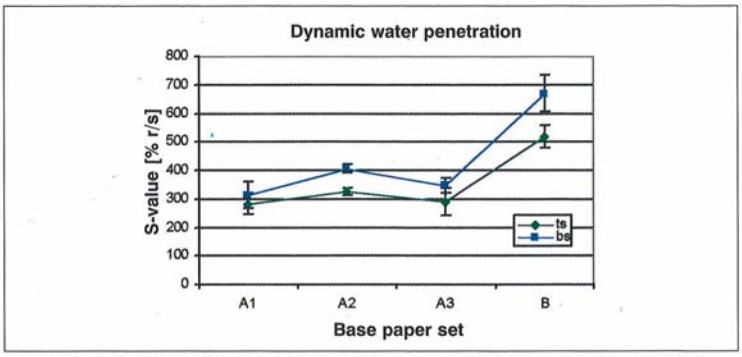

Figure 9: EMCO Dynamic water penetration results of base papers. Base B has highest S-value, correlating to highest water penetration rate[2].