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FACTORS IN THE BLADE COATING PROCESS WHICH INFLUENCE THE COATING MASS DISTRIBUTION

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ABSTRACT

Many printing papers are pigment coated in order to obtain a paper surface with superior printing properties. To achieve this it may be assumed that a coating layer of uniform thickness or mass is extremely important.

A soft X-ray technique has been developed in order to study the coating mass distribution on coated papers. In order to demonstrate the significance of this technique a wood-free and a wood-containing base paper were coated in a pilot coater. On the wood-containing base paper, blade coating with a flooded nip unit was compared with coating in a short dwell time (SDTA) unit. In the former unit, two blades of the same thickness but with different tip areas were used. The result indicated that the most uniform coating layer was obtained when the coating was performed in the flooded nip coater and with a blade of low tip area. This is interpreted as being due to a high specific load on the base paper when it passes under the blade tip, which smoothes out the irregularities in the base paper surface so that the coating film flowing out under the blade tip and the corresponding coating layer are of uniform thickness or mass.

On the fine paper the effect of the strategy of drying the coating layer has been investigated. It was found that the coating layer is redistributed during its consolidation pro-

cess, which is interpreted as being due to movements in the base paper, as a result of the water pick up from the wet coating layer which swells its fibers and break bonds between them.

The coated fine paper was printed in a sheet-fed offset press and the mottle in the print was evaluated. The correlation between the print mottle and the coating mass distribution was very good.

INTRODUCTION

Paper is pigment coated in order to obtain a surface with improved printing properties. Briefly, the coating process involves the application to the paper of an excess of a coating colour which contains pigment and binder. The excess is then scraped off, generally with a doctor blade, leaving a coating layer with a weight of typically 10 g/m² (dry), which corresponds to a thickness of approx. 7 µm. When the excess of coating colour is removed with a doctor blade, the coating method is denoted "blade coating". This coating method is the one most widely used.

The paper surface is rough. The average depth of the profile of a base paper for light weight coated paper is approx. 10 µm when measured with a profiler instrument in which the paper is scanned with a pick-up which does not compress the surface to any significant degree. Measured with the PPS-instrument, which compresses the paper surface during the test, the surface roughness of the same paper is approx. 5 µm. Surface roughness and profile depth, which are here treated as measures giving similar information, are defined in Fig. 1. For reasons of simplicity a sinusoidal profile is assumed. Light weight coated paper is generally denoted LWC.

In blade coating, the coat weight is controlled by varying the pressure applied on the blade, which presses the blade tip against the paper. In the case of a bevelled blade, the coat weight increases when the pressure on the blade is decreased. When coating LWC at 1000 m/min, the load on the blade is approximately 500 N/m, and the pressure under the blade tip 1000 kPa (1,2). The base paper is compressed when it passes under the blade tip.

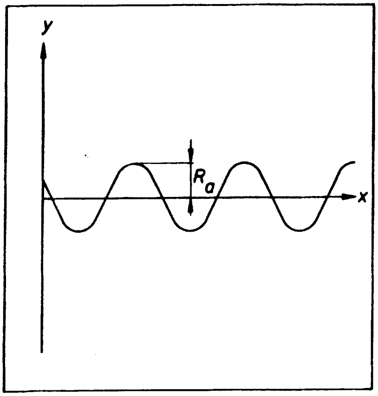

Fig 1 – The surface profile of the paper surface in a x-y diagram. For sake of simplicity, the profile is here assumed to be sinusoidal shaped. R_a is here defined as the surface roughness of the paper.

The gap developed between the paper and the blade when it passes under the blade tip is one factor which determines the coat weight in blade coating (2,3,4) The volume associated with this gap is given roughly by the product of the thickness of the blade and the area of the slit between the blade and the base paper defined by the borders of the two viewed in the machine direction. Since the base paper is rough, its border will be irregular. The coating layer will correspondingly exhibit a mass or thickness variation since more coating will in principle be applied to the valleys of the base paper than to the surrounding hills. The surface roughness which is relevant here will depend on the compression of the base paper under the blade tip.

The following idealized example gives an idea of the magnitude of the mass or thickness variation. Assume that a coat weight of 10 g/m² (dry) corresponding to a thickness of 7 µm is applied to a paper with a surface roughness of 5 µm with a sinusoidal profile as illustrated in Fig. 1. To obtain an average coat weight of 10 g/m^2, the coat weight must vary between 17.1 g/m^2 in the valleys and 2.9 g/m^2 on the hills. The variation in coat weight may thus be considerable.

The properties of the coated sheet are to a great extent determined by the conditions prevailing during the consolidation of the coating layer (5,6). A factor of importance here is the coat weight, which controls the ratio of the amount of water drained into the base paper to the amount of water evaporated in the dryer before the point of immobilization of the coating layer is reached. This ratio may influence both the bulk structure of the dry coating layer (5) and the enrichment of binder in the coating surface (6,7). Consequently, an uneven mass distribution of the coating layer may cause both an uneven bulk structure of the coating layer and an uneven binder distribution in the coating surface, both of which may be expected to affect the print quality in a negative manner. An uneven binder distribution in the coating surface is generally considered to cause a mottled offset print.

An uneven mass distribution of the coating layer may however not only influence the print quality in this indirect manner. The surface roughness of the coated sheet may for instance be affected by the mass distribution of the coating layer, as illustrated in Fig. 2. The more uniform the coating layer the rougher will the coated sheet be and this will affect the ink transfer. Furthermore, the ink setting may be affected by the mass distribution of the coating layer. Ink setting depends on the separation and pick-up of the mineral oil phase of the printing ink by the pores in the coating layer. In order for this process to proceed in a uniform manner throughout the coating layer, not only is a homogeneous pore structure required in the coating layer but the mineral oil should also have access to a sufficient pore volume. If this is not the case in areas of low coat weight, the mineral oil pick-up in these regions will differ from the pick-up in the surrounding areas of high coat weight, the difference being that the mineral oil will be distributed between the pores in the coating layer and those in the base paper beneath it instead of being distributed solely in the coating layer.

Another aspect of the importance of a uniform coating is that it is beneficial for the appearance of the final product if the coating layer covers the substrate evenly, especially if the substrate is less bright. An extreme, but important, example of this is coated unbleached board.

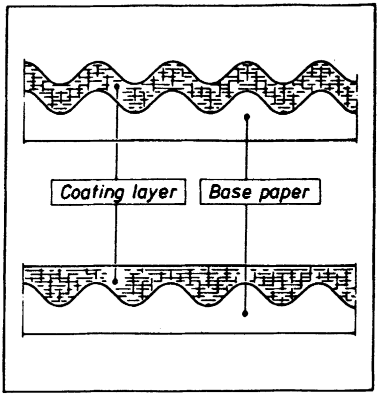

Fig 2 – (a) A coating layer of narrow mass distribution which follows the contour of the base paper, gives a rougher sheet than (b) a coating layer of broad mass distribution which tends to fill out the voids in the base paper surface.

A uniform profile in the properties of the coating layer is required in order to obtain a coated sheet with good printing properties (8,9,10), and a precondition for achieving this is a coating layer of uniform mass distribution.

This paper presents results obtained by a soft X-ray radiograph technique (10,11) which has been developed to determine the mass distribution of the coating layer on one-side coated material. This technique has shown how the mass distribution of the coating layer depends on the blade geometry and type of blade coater as well as on the conditions in the dryer of the coater. A correlation between the mass distribution and the print mottle in a full-scale sheet-fed offset printing trial is also reported.

EXPERIMENTAL

Coating of the base papers

Two types of coated papers, one fine paper and one LWC, were studied. The coating was performed on a pilot coater equipped with a flooded nip and a short dwell time applicator unit. The latter is usually denoted SDTA unit. The machine speed was 1000 m/min and the coat weight was approx. 11 g/m² unless otherwise specified. The coated paper were dried to a moisture content of 5.0 %.

The base paper for the fine paper was coated with a latex-based clay colour while the base papers for the LWC-paper was coated with a starch-based clay colour.

After being coated, the paper was supercalendered in an eleven-nip pilot supercalender, at a speed of 450 m/min under a linear load of 296 kN/m. The steel rolls were heated to 70, 130, 130, 100, 100 and 70 °C respectively from top to bottom.

The coating formulation, like the coating colour and base paper data, are given in Table 1.

	LWC	Fine paper
Clay	100	100
Starch	7	
Carboxymethyl cellulose		1
SB-latex	5	12
Glyoxal	0.7	0.4
Optical brightener	0.2	0.5
Stearate	0.6	0.5
Solids, %	61.0	58.2
Viscosity, Brookfield 100 rpm, mPas	1180	910
pH	7.7	7.7

Clay, SPS from ECC, England
Starch, H-30 from Raisio, Finland
Carboxymethyl cellulose, Finnfix FF5 from Äänekoski, Finland
SB-latex, DL526 from Dow Chemical, Switzerland
Glyoxal, Glyoxal T from BASF, Germany
Optical brightener, Bankophor P from Bayer, Germany
Stearate, Nopcote C104 from Nopco, USA

Base paper: 1) Base paper for LWC, wood containing unsized, 39.0 g/m^2

2) Base paper for coated fine paper, woodfree, acid sized and surface sized, 63.0 g/m^2.

Table 1. Coating colour and base paper data.

A schematic picture of the pilot coater, including some relevant data is shown in Fig. 3

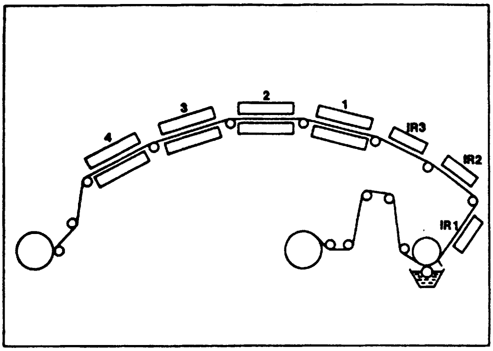

Fig 3 – Design of the pilot coater. IR1, IR2 and IR3 are electrically heated IR-dryers each 1 m in length. 1, 2, 3 and 4 are gas-heated air-foil dryers, each 4 m in length. Distance blade to IR-dryer 1 = 1 m, blade to hot air dryer 1 = 8.2 m.

Soft X-ray radiography

The coated side of the sheet or the corresponding side of the base paper was brought into contact with an X-ray film (Agfa Structrurix D4P) in a special frame and placed in the X-ray cabinet (Philips MG 104C) for exposure. The exposure time was 16 min for the fine paper and 8 min for the LWC, with a voltage of 10 kV and a current of 5 mA. The same times were used for the corresponding base papers.

Evaluation of X-ray radiograms and test prints

The variation in blackness of the X-ray radiograms and the variation in print density (print mottle) of the prints on the coated material has been quantified with an IBAS Kontron image analyser. The level of the blackness or print density is evaluated as well as the spatial variance. The variance is also subjected to a frequency analysis which makes it possible to estimate the size distribution or the character of the variation (12,13).

INTERPRETATION OF X-RAY RADIOGRAMS ON ONE SIDE COATED PAPER

The absorption of X-rays by the paper is determined by the mass through which the X-rays travel and the mass absorption coefficient (11), according to the expression:

$$I = I_o e^{-\mu v} \tag{1}$$

where I = X-ray intensity leaving the sample
I_o = incident X-ray intensity
μ = mass absorption coefficient
v = mass of the sample

The intensity of the X-rays transmitted through the areas of low grammage is greater than that of the X-rays passing through regions of high grammage, and consequently the film will be blackened more in the areas in contact with the low grammage regions of the paper. The blackness distribution of the film is therefore a direct measure of the mass distribution of the paper (11). All results relate to the mass distribution, but if the density of the coating layer is fairly constant, any measure of the mass distribution is also a measure of the thickness distribution of the layer.

To determine the mass distribution of uncoated paper, β-rays and visible light have also been used as illumination sources (14,15).

The blackness distribution of a radiogram from a coated paper contains contributions from both the base paper and the coating layer. The interpretation of such a radiogram is then somewhat complicated since the variances of the masses of the coating layer and of the base paper are likely to be correlated, so that the variance of the mass of the coated paper will not be equal to the sum of the variances corresponding to the coating layer and base paper. Instead, the assessment of the mass distribution of the coating layer may require a covariance analysis (16).

The need for this is illustrated in Fig. 4 which shows for a number of rolls from the same delivery of base paper for LWC that there is a fairly good correlation between the variance of the mass of the base paper and the surface roughness. If it is assumed that blade coating is a levelling coating method (2,3,4) where more coating is applied to the valleys than to the hills, then there will clearly be a correlation between the mass distribution of the coating and surface roughness of the base paper.

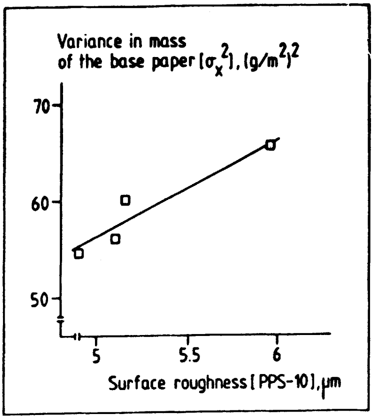

Fig 4 – The variance in mass of the base paper as a function of the PPS-10 surface roughness.

Hence the following expression is relevant:

$$\sigma_w^2 = \left(\frac{\partial w}{\partial x}\right)^2 \sigma_x^2 + \left(\frac{\partial w}{\partial y}\right)^2 \sigma_y^2 + 2k\left(\frac{\partial w}{\partial y}\right) \sigma_x \sigma_y \qquad (2)$$

where σ^2 = variances in w, x and y respectively
k = correlation coefficient between the variations in x and y
w = grammage of the coated paper
x = grammage of the base paper
y = coat weight

Since w = x + y, the derivatives $\partial w/\partial x$ adn $\partial w/\partial y$ will be equal to unity. Consequently eq. (2) can be written

$$\sigma_w^2 = \sigma_x^2 + \sigma_y^2 + 2k\sigma_x\sigma_y \qquad (3)$$

It has been suggested that the ratio of the variance of the mass of the coated paper to that of the base paper is a measure of the degree of contour coating (17). This is based on the fact that, if a base paper with variance in mass σ_x^2 is coated and if the coating is uniform in thickness (and density), then the variance σ_w^2 for the coated paper will be identical to σ_x^2 for the base paper. If the ratio $\sigma_w^2/\sigma_x^2 = 1$ then a perfect contour coating is indicated. Any deviation from unity may thus be considered to be a measure of the deviation from this condition, and in many cases it probably represents a good indirect measure.

A further complication is that the mass absorption coefficients of the coating layer and of the base paper differ from each other.

The radiograms include reference scales which transform the measured blackness values into mass (grammage), but this transformation is not valid if the X-rayed material contains plies of different compositions and of different mass absorption coefficients.

The reference scale used here assumes wood fibres to be the absorbing material, so that the blackness and variance in blackness of the radiograms of the base papers can be directly transformed into mass and variance in mass. This cannot, however, be done with the variance in blackness of the coated paper radiograms since the paper and the coating have different mass absorption coefficients. However, since both the mass of the base paper and of the coating layer are known, the sought variance is easily obtained by a simple normalization according to:

$$\sigma_w^2 = \sigma_{w*}^2 \left(\frac{w}{w*}\right)^2 \qquad (4)$$

where $\sigma^2_{w^*}$ = variance in w^*
w^* = apparent grammage of the coated paper read on the radiogram

In Fig. 5 the apparent grammage of the coated LWC-paper, read on the radiograms, is plotted vs the real grammage, which has been changed by varying the coat weight in the range 8-12 g/m². The grammage of the base paper was 39 g/m². In the figure the intercept at zero coat weight, i.e. the reading of the apparent base paper grammage on the radiogram, corresponds to the true grammage and the apparent coat weight reading corresponds to 4 times the true coat weight, which implies that the absorption coefficient of the coating layer is four times that of the base paper (cf. eq. (1)).

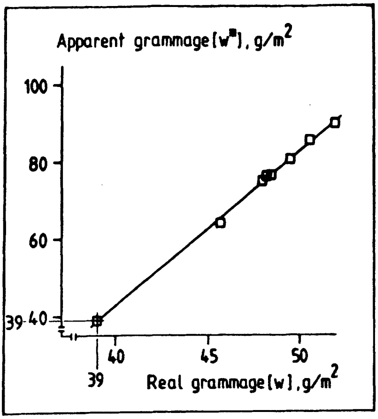

Fig 5 – The apparent gramamge recorded on the X-ray radiogram as a function of the grammage of the coated paper.

Consequently the reading on the radiogram of the apparent grammage of the coated paper (w^*) may be expressed by the relation

$$w^* = x + 4y \qquad (5)$$

where x and y are the true grammages of the base paper and the coating layer respectively.

Differentiating w* with respect to x and y gives $\partial w^*/\partial x = 1$ and $\partial w^*/\partial y = 4$. Inserting these values in eq. (2) gives the expression:

$$\sigma_{w^*}^2 = \sigma_x^2 + 16\sigma_y^2 + 8k\sigma_x\sigma_y \qquad (6)$$

Combining equation (6) with equations (3) and (4) leads to the following expression for the mass distribution of the coating layer:

$$\sigma_y^2 = \frac{1}{12}\{3\sigma_x^2 - \sigma_{w^*}^2\ [(\frac{2w}{w^*})^2 - 1]\} \qquad (7)$$

All the variables on the right-hand side of the expression are known and σ_y^2 can be evaluated.

THE EFFECT OF BLADE CONFIGURATION AND MACHINE SPEED ON THE COATING MASS DISTRIBUTION

When coating is carried out with a bevelled blade, it has been observed that the surface roughness of the coated sheet increases when the machine speed is increased, although the subjective impression is that the surface becomes more homogeneous when the machine speed is increased (18), Fig. 6. At high machine speeds the coating surface looks even but is rough, whereas at low machine speeds the opposite relation applies. Based on these observations, the following simple model of the blade coating process may be proposed.

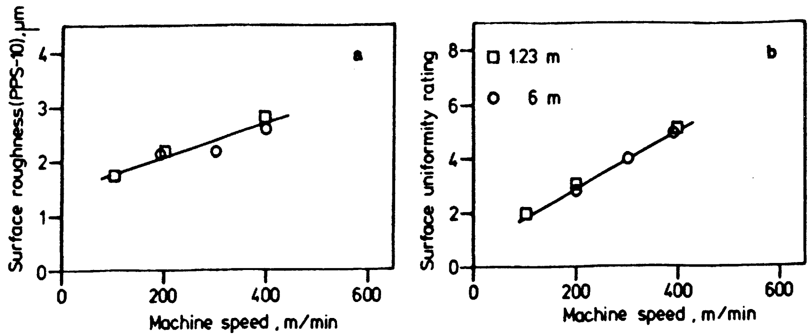

Fig 6 – The PPS-10 roughness (a) and the subjective impression of surface uniformity (b) of coated board as functions of the machine speed. The distance between the blade and the dryer was either 1.23 m (□) or 6 m (o).

When the machine speed is increased the blade pressure must be increased in order to keep the coat weight constant. This increase in the blade pressure may be assumed to increase the compression of the base paper when it passes under the blade tip and this evens out the roughness in the base paper surface. Hence the coating colour film passing under the blade tip will be more uniform in thickness if the base paper is compressed to a greater degree when it passes under the blade tip. After the blade the compression is released and the base paper recovers in a movement in which the coating layer is also incorporated, Fig. 7.

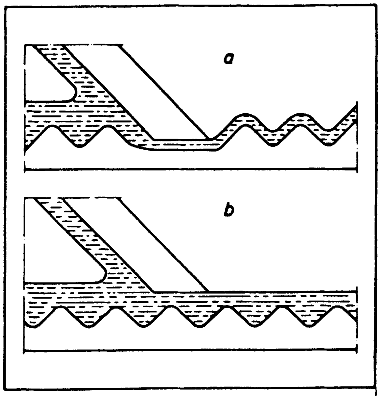

Fig 7 – A simple model of the blade coating process and how the coating layer is formed a) at high load and b) at low load on the base paper.

In order to test the relevance of this model and simultaneously check the applicability of the X-ray technique to determine the mass distribution of the coating layer, a base paper for LWC was coated with a starch-based clay colour with two different blade configurations in a flooded nip unit. For comparison, coating was also carried out with a SDTA unit. The two blade configurations, which are shown in Fig. 8, were:

1. A normal coater blade with a thickness of 0.508 mm.

2. Two 0.254 mm blades glued together, displaced approx. 1 mm in the length direction. The tip of this sandwich construction is identical to that of one blade having a thickness of 0.254 mm.

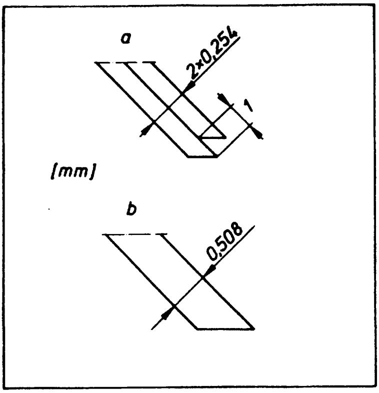

Fig 8 – The two blade configurations tested a) two 0.254 mm blades glued together and b) a normal 0.508 mm blade.

Since the two blade configurations described above have the same thickness, they also have the same stiffness. Therefore, the two blades will be equally bent at the same blade pressure. It may therefore be assumed that the two blade configurations will give the same coat weight at the same blade pressure (2).

An important difference between the two blades is the contact area with the base paper, which is twice as large with the 0.508 mm as with the 2 x 0.254 mm blade. At a given coat weight and consequently at the same blade pressure and curvature of the blades, the specific load (pressure) on the base paper when it passes under the blade tip is twice as high with the 2 x 0.254 mm as with the 0.508 mm blade. Consequently, the double 0.254 mm blade will compress the base paper more and will more effectively even out the roughness in the surface than the 0.508 mm blade. Hence, it is reasonable to expect that coating with the 2 x 0.254 mm blade will give a coating layer with a more even thickness and a narrower coating mass distribution.

The assumption that the same blade pressure on the two blades will give the same coat weight assumes that the coat weight is solely controlled by the impulse and pressure forces created by the mass flow of the coating colour when it strikes the inside of the blade (2). These forces are identical on the two blades. Forces generated under the blade tip (18,19) which affect the coat weight are here assumed to be of minor importance and are therefore not considered.

The flooded nip and the SDTA coater were compared because SDTA-coated paper is generally known to have a rougher surface structure than flooded nip coated paper, and it has been demonstrated that the coating layer of flooded nip coated paper has a narrower mass distribution than that of SDTA-coated paper (9,20).

The X-ray analysis of the mass distribution of the coating layer of the LWC-papers coated with the two blade configurations fully confirms these expectations. In Fig. 9, where the variance in mass (coat weight) of the coating layer is plotted against the coat weight, it is evident that at a given coat-weight the variance in mass of the coating layer is less when the 2 x 0.254 mm blade is used. The highest variance is associated with the SDTA-coater.

Fig. 9 also shows that the variance decreases when the coat weight is decreased. Consequently, the lower the coat weight the greater is the degree of contour coating. The coat weight is controlled by the blade pressure and, since it is increased to reduce the coat weight, the base paper will be more compressed under the blade tip at low coat weight than at high.

In another pilot coating trial with the same base paper and the same coating colour as in the previous example, it was found that the mass distribution of the coating layer was more narrow on paper coated at 1000 m/min than on that coated at 500 m/min. This is probably also due to the compression of the base paper when it passes under the blade tip since the blade pressure is higher at 1000 m/min than at 500 m/min.

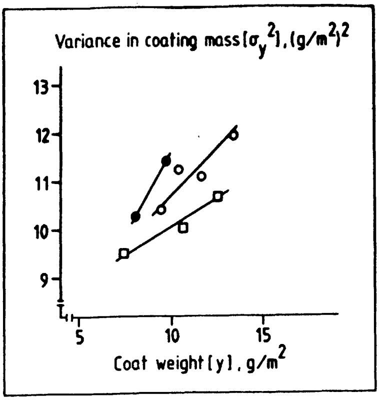

Fig 9 – The variance in mass of the coating layer as a function of the coat weight for coating layer formed in the SDTA unit (•) and in the flooded nip unit. In the latter case with two blade configurations a 0.508 mm blade (o) and a 2 x 0.254 mm sandwiched blade (□).

The magnitude of the compression of the base paper when it passes under the blade tip is determined not only by the load on the paper, the time under the blade and the viscoelastic properties of the base paper, but also by how these properties are affected by the water pick-up from the coating layer which softens the fibres (21,22). This water pick-up increases when the machine speed is decreased.

THE INFLUENCE OF THE CONDITIONS IN THE DRYER

It is generally known that the conditions in the dryer of the coater affect the quality of an offset print on the coated paper. It is not known whether these also affect the mass distribution of the coating layer on the sheet and whether there is a link between the mass distribution and offset print quality. To investigate this, a wood-free base paper was blade coated with a latex-based clay colour in a flooded nip unit, the coat weight being approx. 11 g/m² and the machine speed

1000 m/min. The coating layer was dried with four hot-air hoods or with a combination of these and infra red (IR) dryers installed before the hot-air hoods. The conditions are summarized in Table 2.

IR-dryer	Temperature/velocity of the impingement air in the hot-air hoods, °C/ms^{-1}			
	Hood No.			
	1	2	3	4
		First experiment		
	238/66	175/30	212/42	202/41
	252/43	172/30	213/42	197/41
	178/20	170/27	233/42	198/31
	189/41	181/31	235/42	216/31
	125/42	186/31	228/42	284/45
		Second experiment		
	183/35	234/58	226/42	231/28
	179/38	226/45	231/42	310/48
	181/40	176/48	259/43	252/46
	179/38	166/44	238/40	235/37
	182/40	110/38	249/43	291/42
	178/40	120/18	269/41	260/48
		Third experiment		
3	214/39	127/41	236/40	137/26
1+3	212/39	117/38	242/40	154/26
1	215/45	122/38	223/39	168/48

Table 2. Conditions in the dryer of coater during the trials.

In the first experiment, the evaporation rate in the first hot air hood was varied by varying the temperature of the impinging air. The conditions in the second and third hoods were kept constant. The final moisture content of the coated paper, 5.0 %, was controlled with the fourth hood. With this evaporation profile, it can be assumed that the consolidation of the coating layer has ceased before the paper exits from the third hood i.e. it takes place under controlled conditions.

In the second experiment, the evaporation rate was varied in the second hot-air hood. The conditions in the first and third hoods were constant and the end moisture was again controlled in the fourth hood.

In the third experiment, IR-dryers were included before the hot-air hoods, and the conditions in hot-air hoods 1 and 2 were kept constant. When the IR-dryer was switched on, the evaporation in the third and fourth hot-air hoods was reduced in order to maintain the final moisture content of the coated paper at 5.0 %.

Fig. 10 illustrates how the mass distribution of the coating layer depends on the temperature of the impinging air in the first and second air hoods. The curves have a similar shape but are displaced relative to each other. It is interesting to note that the mass distribution of the coating layer is affected by the conditions in the coater dryer, i.e. that the coating layer is redistributed during its consolidation process. Similar results have been reported by Bown et al (20).

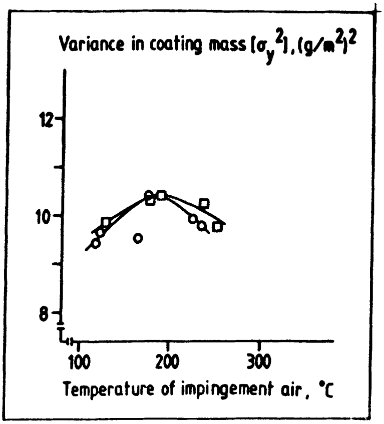

Fig 10 – The variance in mass of the coating layer as a function of the temperature of the impinging air in a) hood no 1 (□) and b) hood no 2 (o) in the hot air dryer.

When water is applied to paper, as in the coating colour, the fibres are swollen and plasticised. Bonds between the fibres are also broken (22,23,24). These factors, which release internal stresses and increase the volume of the paper, result in an irreversible movement in the plane of the paper as well as perpendicular to the plane. This movement is noticed as an increase in the thickness and in the surface roughness of the paper, which leads to an increase in the area of the surface, i.e. of the boundary between the base paper and the coating layer.

In principle there are two ways in which the coating layer can redistribute its mass during the consolidation process.

1) If the wet coating layer follows the movement of the surface of the base paper, the area of the coating layer surface and the interfacial area of the coating layer/base paper boundary will increase. Since the surface tension of the wet coating layer strives to minimize the area of the surface of the coating layer, the colour must be redistributed simultaneously from the hills in the base paper surface to the valleys, Fig. 11a.

2) If the wet coating layer does not follow the movement of the surface of base paper then, since the coating layer has a larger area to cover due to the increase in the surface area of the base paper, a redistribution of material in the bulk of the coating layer must take place, Fig. 11b.

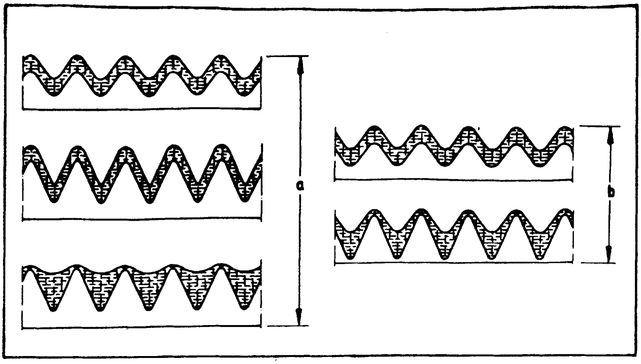

Fig 11 – Two suggested processes of redistribution of the coating layer during its process of consolidation a) the coating layer follows the movement and b) does not follow the movement in the base paper surface.

When the temperature of the impinging air is increased, the evaporation rate will simultaneously increase. As a consequence the consolidation process will proceed faster and the amount of water drained into the base paper up to the immobilization point of the coating layer will be less. An implication of this is that the time for the water to interact with the fibre material in the base paper will decrease when the evaporation rate is increased, although the temperature of this water will be higher.

Fibre swelling and fibre debonding are diffusion-controlled processes (24) and are therefore in some way controlled by the square root of the product of the diffusion coefficient D and the time t during which the diffusion process proceeds, (25). Since D increases and t decreases when the temperature is increased, curves like those shown in Fig. 10 might be expected, the increase in roughness of the boundary region between the coating layer and the base paper being observed as an increase in the variance of the mass of the coating layer as a consequence of the redistribution of the coating layer.

Table 3 shows how the mass distribution of the coating layer is affected by three different IR-drying strategies. The application of IR-drying prior to the hot-air hoods makes the mass distribution of the coating layer more narrow.

When drying is carried out with IR and hot-air, the evaporation starts a shorter time after the coating colour application than with hot air drying alone, since the IR-dryers are installed prior to the hot-air dryer. Hence the consolidation of the coating layer will cease earlier and, for the same reasons as outlined above, a coating layer with a more uniform coat weight distribution will be obtained.

IR-dryer switched on	Coating mass distribution variance in mass, $[g/m^2]^2$
1	9.47
3	9.75
1+3	9.20
none (hot air drying only)	>9.80

Table 3. Effect of IR-drying on coating mass distribution. The comparison IR- and hot air drying is made on coatings applied on a base paper of equal variance in mass.

THE RELATION BETWEEN THE MASS DISTRIBUTION AND THE DEGREE OF PRINT MOTTLE

Test printing

The coated fine paper was test printed at a speed of 5000 copies/h in a sheet-fed Roland Favorite offset press, Fig. 12. In the Roland Favorite press, printing units 1 and 2 and printing units 3 and 4 are arranged in pairs with common backing rolls. Consequently, the distance between the 1st and 2nd printing units and between the 3rd and 4th is short compared with the distance between the 2nd and 3rd printing units.

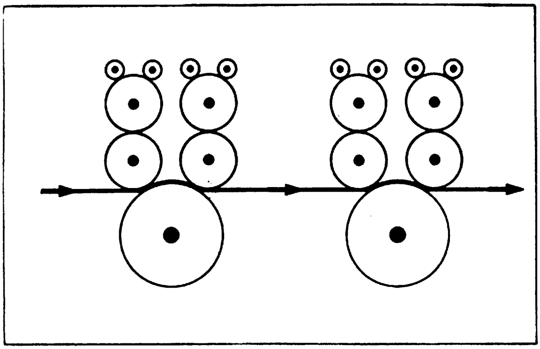

Fig 12 – Design of the Roland Favorite sheet-fed offset press.

By studying the development of the mottle in the prints from the four printing units, the cause of the mottle may be deduced from a graphic arts point of view. To simplify the study, the same printing ink, a cyan from Winter, was printed in all four printing units, identical squares 60 x 125 mm with screen dot densities 25, 50, 75 and 100 % being printed onto the paper. The design of the printing plate is shown in Fig. 13. The mottle of the prints was evaluated with the image analyser in a manner identical to that used for the X-ray radiograms. The mottle is here expressed as the variance in print density in the 2-4 mm range. The human eye is most sensitive to disturbances of that size (26).

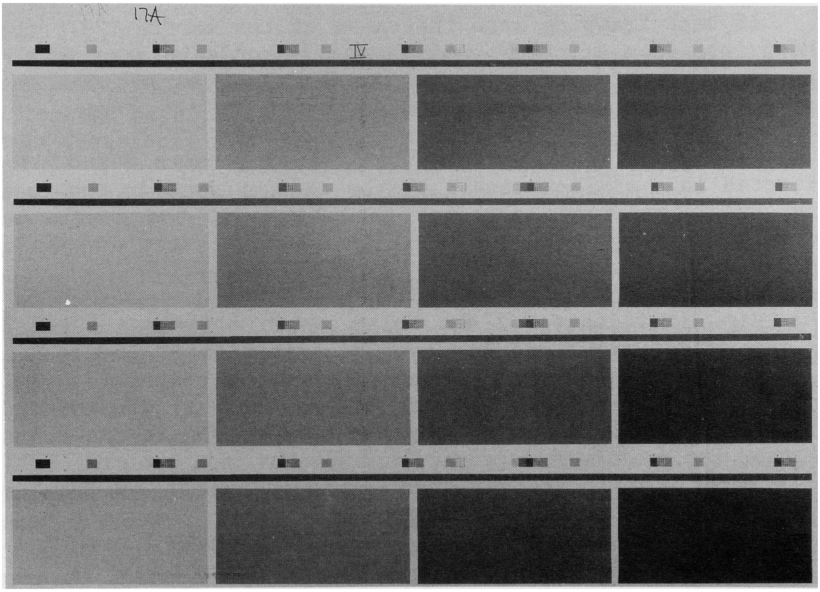

Fig 13 – Lay-out of the printing form. The same cyan ink was printed in all print units.

The prints from printing units 2 and 4 were more mottled than those from printing units 1 and 3. Since the distance, and consequently also the time between printing units 1 and 2 and between printing units 3 and 4 is shorter than that between printing units 2 and 3, it may be assumed that this time is too short for the fountain solution to be absorbed by the coating layer before the sheet is printed in the following printing unit (i.e. units 2 or 4). Hence those prints are mottled.

The fountain solution transferred to the coating surface in printing unit 2 has however time to be absorbed into the coating layer before reaching printing unit 3. The coating may then be considered to be dry as in the first printing unit where no water is applied to the surface before printing. Hence the prints from those two printing units are not mottled (27). The fountain solution used here was adjusted with isopropanol.

If back-trapping were the cause of the mottle (28), then the prints from printing units 1 and 2 should be more mottled and not those from printing units 2 and 4, as was the case here.

The mottle in the prints from printing units 2 and 4 was affected in a similar manner by the changes made in the coating drying strategy, although the degree of the mottle was somewhat higher in the prints from printing unit 2 than in those from printing unit 4.

Fig. 14 illustrates the relationship between the mottle in the offset print and the mass distribution of the coating layer on the sheet, both expressed by their respective variances. The correlation is very good and the narrower the mass distribution of the coating layer the more even is the print. Whether the coating mass distribution affects the print mottle in a direct or indirect manner can however not be answered within the scope of this investigation.

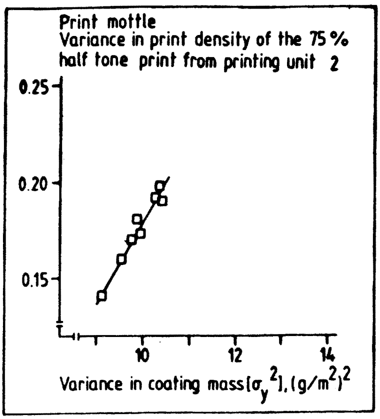

Fig 14 – The print mottle expressed as the variance in the print density in the 2-4 mm range as a function of the variance in mass of the coating layer.

SUMMARY

A soft X-ray radiography method has been developed in order to quantify the mass distribution of the coating layer on coated paper. Using this method it has been shown that the mass distribution of the coating layer is affected both by the events under the blade tip where the coating layer is formed and by the conditions in the dryer of the coater.

Under the blade tip the base paper is compressed and this evens out the irregularities in its surface. This determines the thickness profile of the coating film which flows out in the slit between the base paper and the blade and consequently also the mass distribution of the coating layer. The more the base paper is compressed the more uniform will the coating layer be.

The drainage of water from the wet coating layer into the base paper during the consolidation of the coating may be presumed to swell the fibres in the paper and to break bonds between them. This induces movements in the paper which redistribute the coating layer during its consolidation. These movements and the resulting mass distribution of the coating layer are affected by the conditions in the dryer.

The importance of being able to measure and to control the mass distribution of the coating layer is illustrated by the excellent correlation between the mottle in the offset print and the mass distribution of the coating layer. Print mottle is often considered to be the most important print quality factor.

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Transcription of Discussion

FACTORS IN THE BLADE COATING PROCESS WHICH INFLUENCE THE COATING MASS DISTRIBUTION

G. Engstrom, P. A. Johansson, M. Rigdahl and P. Norrdahl

Errata
Please note the following erratum Vol. 2 p. 930 Equation (2) should be:-

$$\sigma_w^2 = \left(\frac{\delta w}{\delta x}\right)^2\sigma_x^2 + \left(\frac{\delta w}{\delta y}\right)^2\sigma_y^2 + 2k\left(\frac{\delta w}{\delta x}\right)\left(\frac{\delta w}{\delta y}\right)\sigma_x\sigma_y$$

A. Ibrahim, PAPYRUS

Just a comment. In your last equation no. 7 on page 933, there is a difference between the one you showed us today and the one in the text. Could you please tell us which one is correct?

G. Engstrom STFI

The one which is printed in the book is correct.

M. Steen, Norwegian Pulp & Paper Research Institute

My question refers to your analysis of variance. Could you use the same technique to get a power spectrum both of the variation of your coating as well as the fibres? Is there any correlation between sheet formation and the coated mass distribution?

G. Engstrom

We obtain the variance in the form of a power spectrum, so in principle it would be possible to relate defects in the base paper to defects in the coating layer. Such a study would indeed be meaningful but so far we have not done any. This is partly due to the difficulty in obtaining a good contrast in soft X-ray radiograms, which may influence the details in the power spectrum.

Dr. H.L. Baumgarten, PTS

What is the relation between the test area used to determine the coating mass variance and printing mass variance on the one hand and the coating blade thickness on the other? Has a test of equal size been used? What was the size of the test area in relation to the blade thickness? This data is very important, since the influences of different blade thickness on the above variances were to be identified. The above questions would also seem relevant in view of the sketch of the applicator system as shown in the conference papers and which equates blade thickness and coat thickness, although the blade thickness is about 20 times the coat thickness.

G. Engstrom

The diameter of the measurement spot, or the spatial resolution in the image analyzer when we measure the mass distribution from the radiogram or the mottle in the print, is 0.1mm. The mass distribution and the mottle were obtained from the image analysis as the spatial variance in the wavelength range 0.25 - 16 mm.

In a dynamic situation, the base paper does not see the blade thickness. It sees the projection of the blade in the machine direction. The length of this projection is equal to the length of base paper that has passed under the blade tip. The blade thickness is only relevant in the static case and that is not the case in blade coating.

A. Komppa, The Finnish Pulp & Paper Institute

Did you measure the mass formation of the base paper before coating?

G. Engstrom

Yes we measure the mass distribution of the base paper. We do that on every roll, both at its beginning and at its end. The mean of these measures is used when we calculate the coating mass distribution on coatings applied on that roll.

Dr. K. Ebeling, James River Corporation

Congratulations on a very good paper and for putting some order into this subject. Based on your Figure 14 (page 946), can one draw the conclusion that if the mass variation of the coating layer is below 9 g/m^2, then your modelling problem will not exist, as it is the universal value below which you will not have a model?

G. Engstrom

No, one should not interpret Figure 14 in that way, since the coating mass distribution is certainly not the only factor which affects print mottle. I said in my presentation, that our results did not show whether the print mottle was caused directly or indirectly by the coating mass distribution. Recently, we have quantified the binder distribution in the coating surface of the coated material represented in Figure 14. Since we could not explain the print mottle with the binder distribution in this case, the cause of the mottle seems to be directly controlled by the mass distribution of the coating layer. However, when we coated different base papers, the print mottle rating was not in accordance with the coating mass distribution rating. This shows that in this case the print mottle was caused by factors other than the coating mass distribution.

Prof. D. Eklund, Abo Akademi

I have a question relating to the two blades that you glued together. You state in your paper that one can assume that the two blade configuration will give the same coat weight at the same blade pressure, but do you mean the mechanical force, because if this is so, then the assumption is wrong and you have mis-quoted me. The two blades will give the same coat weight if the compression of the paper is the same. At the same mechanical force, the 0.508 blade will give half the pressure of the 0.254 blade. If you compare the two blades at the same coat weight, the mechanical force must be higher on the thicker blade, but the actual pressure under the tip of the blade will actually be the same in both cases. Can your results not be explained by the longer time under pressure when you use the thicker blade?

G. Engstrom

I said in my presentation that the blade pressure required for a certain coat weight was the same for the two blades. Since the pressure and impulse forces acting on the blade are also the same, it is evident from the force balance on the blade tip that the resulting force acting on the base paper under the blade nip is also the same. Since the contact area between the 0.508 mm blade and the base paper is only half that of the 2 x 0.254 mm blade, the pressure under the 0.508 mm is also half that under the 2 x 0.254 mm blade.

Prof. D. Eklund

Then your results are not in conformity with what I have published, but I suggest that we should discuss this outside of these proceedings.