Precalendering and its effect on paper-coating interaction

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ABSTRACT *Uncalendered and precalendered LWC (lightweight coated) base papers were blade coated in a pilot coater and printed in lithographic offset. The main effect of precalendering was compression of the fiber flocs in the base paper. When the uncalendered and precalendered papers were coated, the fiber flocs expanded upon exposure to the water in the coating color. Expansion was more pronounced on the precalendered base paper, resulting in uneven distribution of coating mass and greater print mottle. Coating mass distribution and print mottle were evaluated through frequency analyses of variances in coat weight and diffuse print reflectance, respectively. The curve describing the frequency distribution for variance of coating mass distribution had the same shape as the frequency-distribution curve for variance in print mottle, demonstrating a strong association between print mottle and unevenness in coat weight.*

KEYWORDS
Blade coating
Calendering
Coating base papers
Coating color
Evaluation
Lithography
Offset printing
Paper stock
Water

Mottled print is a serious problem that commonly occurs when coated paper is printed in lithographic offset. Print mottle has several causes related to both the graphic arts and the coated-paper substrate (*1, 2*).

Binder migration—uneven distribution of binder resulting from an incorrect drying strategy—is generally suggested to be the cause of print mottle (*3-5*). However, binder migration is not the only cause (*6*).

Previous work has shown good correlation between mottle and the distribution of coating mass (*7, 8*). The latter is governed by several factors interacting in a complex manner. The most important factors are probably the coating process (*7, 9, 10*) and the type of base paper (*11, 12*). It also has been reported that the drying process affects the coating mass distribution (*7, 8*).

Paper is coated by applying a coating color that consists of a pigment and a binder dispersed in water. When the base paper is exposed to the water in the coating color, its thickness and surface roughness are increased (*13-17*). The increase in surface roughness, which can also be described as a movement in the base paper surface under and in contact with the coating layer, can affect the coating mass distribution (*8, 10, 11*).

A coating layer with a narrow mass distribution, i.e., a coating layer of even thickness, provides a superior printing surface (*6-8, 12*) as well as uniform optical coverage, which is especially important if the base paper is of low brightness. To obtain such a coating layer, the surface roughness of the base paper must not increase too much as the coating layer consolidates (*6, 7*).

Previous work has shown that the irreversible increase in surface roughness after exposure to water was close to zero for freely dried and uncalendered sheets made from mechanical pulp and was only marginally greater for similarly dried sheets made from chemical pulp (*16*). Another study, which measured the swelling pressures within sheets exposed to water, ranked freely dried and uncalendered mechanical and chemical sheets in the same manner (*17*). The swelling pressure within the sheet can be related to the sum of the reversible and irreversible increases in surface roughness of the sheet. This relationship is valid if the increase in surface roughness is linked to the increase in thickness, which is normally the case (*16*).

The situation was different in the case of calendered sheets. Both the irreversible increase in surface roughness and the swelling pressure were markedly higher and were highest for sheets based on mechanical pulp (*16, 17*). The increase in surface roughness in these sheets was so high that the whole effect of the calendering was lost. Similar results are reported in the literature (*18*). Such results demonstrate the significant effect of precalendering on the properties of the base paper and emphasize that the precalendering operation must be properly balanced if the papermaker is to produce a coated sheet with an optimum quality profile.

This report presents results from a study of precalendering and its effect on the interaction between the base paper and the water in the coating color. Precalendering and coating were performed on a pilot scale under typical process conditions. It was found that changes in the surface of the precalendered base paper affected the distribution of coating mass and increased the mottle in offset prints on the coated material.

Experimental

Precalendering

The base paper used in this study was an LWC (lightweight coated) grade (Feldmühle Beghin Corbehem, France) with a grammage of 50 g/m². The paper had been machine calendered at the mill to a surface roughness (PPS-10) of 6.5 μm on the felt side and 7.2 μm on the wire side. This is a rather high surface roughness for an LWC base paper. The paper was calendered to a more-normal level of surface roughness for LWC (4.7 μm and 5.1 μm, respectively) by passing it through three nips in a ten-roll pilot supercalender. The machine speed was 400 m/min and the line pressure 100 kN/m. Calender rolls were not heated.

Throughout the rest of this report, the base paper that was calendered in the pilot facility is denoted as "precalendered." The machine-calendered base paper as delivered from the mill is referred to as "uncalendered."

Coating

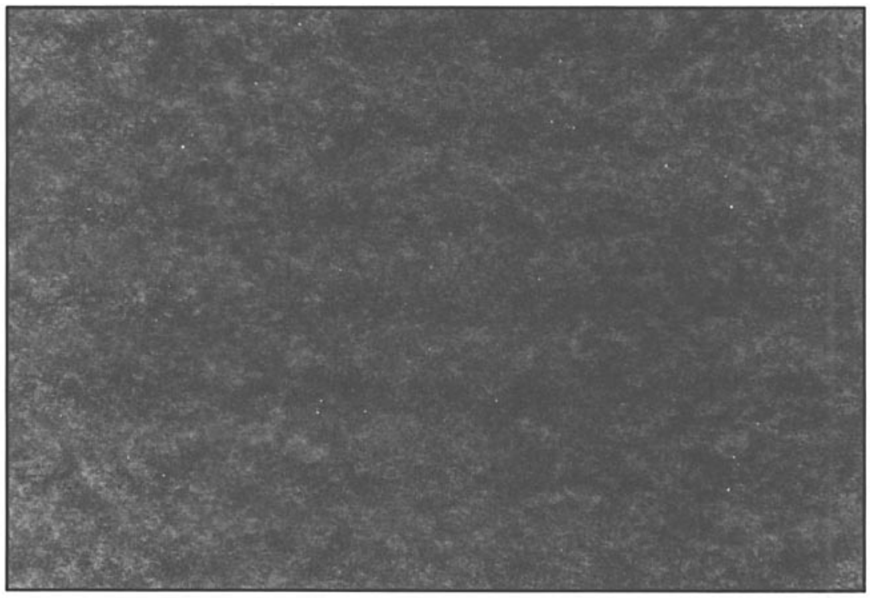
The precalendered and uncalendered base papers were blade coated, with roll application of the coating color in a pilot coater (*19*) at a machine speed of 1000 m/min. Both sides of the sheet

I. Coating formulation and coating-color properties

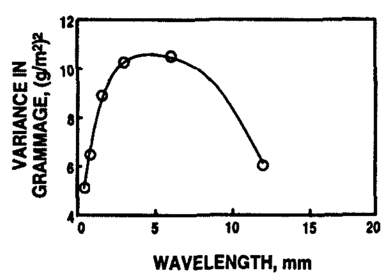
Coating formulation,* parts		
Clay	100	...
Ground calcium carbonate	...	100
Carboxymethyl cellulose	1	1
Styrene-butadiene latex	10	10
Coating-color properties		
Solids, %	60.0	65.0
Viscosity (Brookfield 100 rpm), mPa·s	1400	1600
pH	8.4	9.0

*Trade names and suppliers: clay, SPS (ECC, United Kingdom); calcium carbonate, C95 (ECC, United Kingdom); carboxymethyl cellulose, Finnfix 5 (Metsä-Serla, Finland); latex, SB 023 (Rhone Poulenc, France).

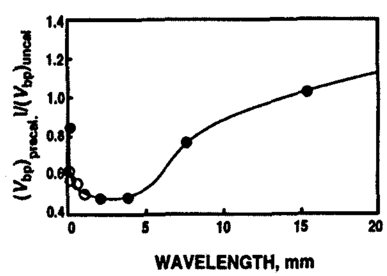
1. Coated precalendered paper after burnout test



2. Variance in grammage of uncalendered sheet as a function of wavelength



3. Ratio of variance in surface profile of precalendered base paper to that of uncalendered base paper as a function of wavelength



were coated, with the felt side coated first using a clay-based coating color. The clay-coated side was the "experimental" side scrutinized in this study. The wire side was coated with a calcium carbonate coating color, mainly for the sake of flatness. The use of two different coating colors made it easier to identify the experimental side of the sheet. Coating colors were prepared in a conventional manner, and coat weight was 11 g/m^2 per side. The final moisture content was 5.0%. **Table I** lists the coating formulations and their associated properties.

After being coated, all papers were supercalendered in the same pilot supercalender that had been used to precalender the base paper. The machine speed was 400 m/min with a line pressure of 300 kN/m. The steel rolls were heated to 80°C.

Printing

The supercalendered material was printed in a sheet-fed four-color Heidelberg GTO offset press at a speed of 5000 copies/h. Stripes—25 mm in width and with screen rulings of 50% and 100%—were printed onto the sheet in different color combinations. The color sequence was black, cyan, magenta, and yellow. The printing ink had the trade name Serie Major (Lorilleux, France).

The mottle in the print was evaluated in the cyan stripe with the screen ruling of 50%. Mottle was evaluated with the help of image analysis by determining the variance in print reflectance. The variance was frequency analyzed and reported over the following six wavelength intervals: 0.17-0.34-0.68-1.4-2.7-5.4-11.0 mm.

Distribution of coating mass

The coating mass distribution was evaluated with a so-called burnout test (*20*). Briefly, this test is performed by immersing the sample in a solution consisting of 25 g/L of ammonium chloride (NH_4Cl) in a mixture of equal parts of water and ethanol. When the sample is saturated, it is withdrawn and the excess solution is allowed to drip off. The sample is then dried under ambient conditions before being transferred to a ventilated oven heated to 225°C.

When the sample is exposed to the heat, the fiber material in the base paper carbonizes and turns black. Against this background, any unevenness in the coat weight of the thin coating layer is clearly revealed, as seen in **Fig. 1**. The mean blackness of the burnout is a measure of the coat weight, and the variance in blackness is a measure of the coat weight distribution. Both measures were evaluated using the same image-analysis technique that was used to measure print mottle. Variance was reported over the following six wavelength intervals: 0.25-0.50-1.0-2.0-4.0-8.0-16.0 mm. These intervals are somewhat longer than those used to evaluate print mottle to accommodate the higher magnification when the image was read.

To obtain the coating mass distribution as the variance in coat weight in units of grams per square meter, calibration material was prepared by coating and calendering sheets on a bench scale. The same base paper and coating color were used as for the pilot coating. Coat weight was varied in the range 5-60 g/m^2. The transformation was performed on burnouts of coated sheets that had been supercalendered.

The mass distribution of the base paper was determined with a β-radiographic technique (*21*). The radiogram was evaluated with the same image-analysis procedure that was used for the burnouts.

Binder distribution

The distribution of latex binder on the coating surface was determined using an ultraviolet technique (*22*). This measurement technique involves scanning a sample area of 60 mm × 63 mm in lines separated by 4 mm. On each line, measurements are performed at intervals of 1 mm. The mean of all measured points provides the latex content in the coating surface, while the variance provides the latex distribution. Because each measuring point represents an area of 1 mm × 4 mm, the variance provides information of a coarse-scale unevenness.

Surface profile

Surface profile was measured with a Perth-O-Meter instrument, which traces the test surface with a fine diamond stylus (*23*). Twenty 58-mm-long tracks were traced at 3-mm intervals. The surface profile was presented as a frequency-analyzed variance separated into the following ten wavelength intervals: 0.04-0.08-0.16-0.32-0.64-1.28-2.56-5.12-10.2-20.5-41.0 mm.

Thickness

Thickness was determined with an instrument developed at STFI (*24*). The instrument measures the true thickness of paper by passing the sheet between two probes.

Surface roughness

Surface roughness was measured with a Parker Print-Surf instrument at a clamping pressure of 10 kp/cm^2.

Results

The base papers in this study were coated on both sides. In the first coating operation, the felt side of the paper was coated with the clay-based coating color. In the second operation, the wire side was coated with the calcium carbonate-based coating color. The first side coated—the clay-coated side—is the experimental side of the sheet, and reported results are for this side. In principle, the properties of the other side developed in an identical manner.

Precalendering the base paper

Precalendering reduced the thickness of the paper by 17%, from 94 μm to 78 μm. Simultaneously, the surface roughness (PPS-10) was reduced from 6.5 μm to 4.7 μm on the felt side and from 7.2 μm to 5.1 μm on the wire side.

More-detailed information about the effect of precalendering on surface roughness can be obtained by comparing the ratio of the variance in surface profile for the precalendered and uncalendered base papers—$(V_{bp})_{precal}/(V_{bp})_{uncal}$—at a given wavelength interval. The lower this ratio is, the greater is the relative effect of the precalendering. A ratio equal to unity indicates that the precalendering did not affect the surface profile within the wavelength range.

The formation spectrum for the uncalendered base paper in **Fig. 2** shows a maximum variance in grammage within the wavelength range just less than 5 mm, indicating the presence of fiber flocs. It is reasonable to expect that precalendering would predominantly compress these fiber flocs in the base paper (*25*).

The ratio of variance in surface profile for the precalendered and uncalendered base papers is plotted in

Fig. 3 against the mean wavelength of the wavelength interval. The ratio attains its lowest value within a wavelength range just less than 5 mm, confirming that it was the hills within this wavelength range that were most compressed by the precalendering.

Coating

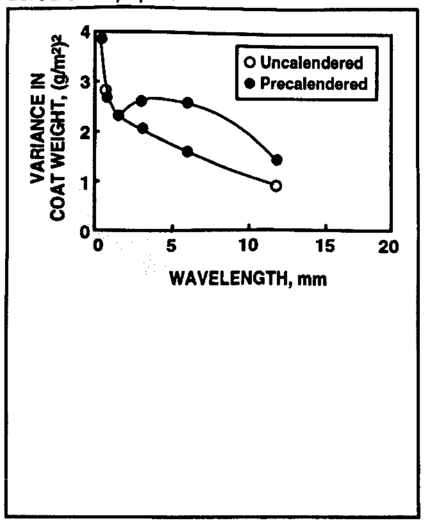
Mass distribution. The subjective impression of the burnout images was that they were more uneven when the base paper was precalendered, indicating that the coating layer was more unevenly distributed on the precalendered paper. If one expects the most even coating layer to be obtained on the base paper with the smoothest surface, i.e., the precalendered paper, this result is confusing.

Figure 4 shows the frequency analysis of the variance in coat weight for the uncalendered and precalendered base papers. The variance in coat weight was greater on the precalendered base paper than on the uncalendered for wavelengths exceeding 1.5 mm. At wavelengths below that level, the variances were the same. Thus the image analysis and the subjective evaluation rate the mottle in the same manner. Figure 4 also shows that the variance in coat weight decreased continuously with increasing wavelength for the uncalendered base paper. For the precalendered base paper, the variance passed through a maximum at a wavelength of about 5 mm. This wavelength range corresponds to the size of the fiber flocs in the base paper, indicating that the coating is more concentrated between the fiber flocs on the precalendered base paper than it is on the uncalendered paper.

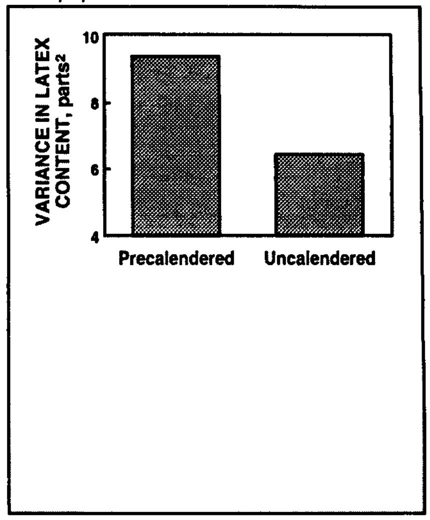
Binder distribution. The binder content at the coating surface is higher at high coat weights than at low. Thus it is expected that an uneven distribution of coating mass would be accompanied by an uneven binder distribution.

Figure 5 shows the latex distribution in the coating surface, expressed as the variance in latex content, for the precalendered and uncalendered base papers. The results show that the latex binder was more evenly distributed on the uncalendered base paper than on the precalendered, which is in agreement with the relationship established for coating mass distributions at longer wavelengths (Fig. 4).

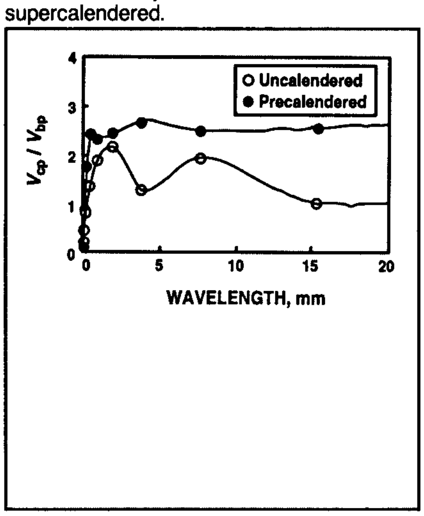
4. Variance in coat weight as a function of wavelength for precalendered and uncalendered base papers



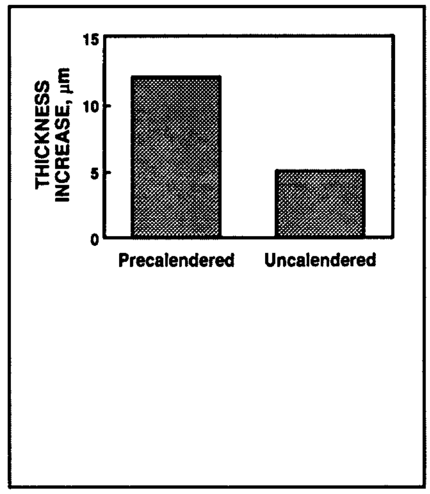
5. Variance in latex content in the coating surface of precalendered and uncalendered base papers



6. Ratio of variance in surface profile of coated paper to that of base paper as a function of wavelength for precalendered and uncalendered base papers. Base papers were coated on only one side and were not supercalendered.



7. Thickness increase of precalendered and uncalendered base papers after coating one side



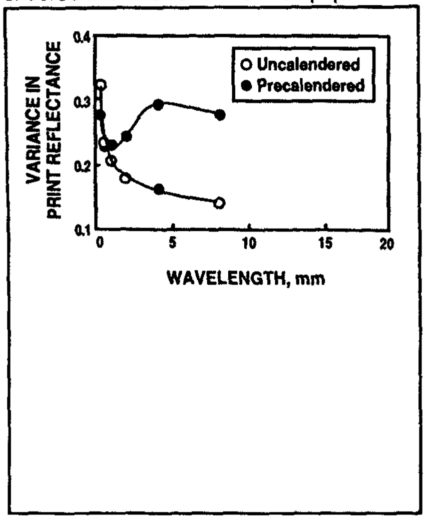
The latex content in the coating surface on both the precalendered and the uncalendered base paper was approximately four parts, whereas the formulation contained ten parts. The conclusion is that latex was transported away from the coating surface as the coating layer consolidated (*4, 6*).

Surface profile. Both the base papers became smoother as a result of the coating. For the precalendered base paper, the surface roughness (PPS-10) decreased from 4.7 µm to 4.5 µm when the felt side was coated. Surface roughness of the uncalendered base paper dropped from 6.5 µm to 5.3 µm. Variance in the surface profiles was affected similarly.

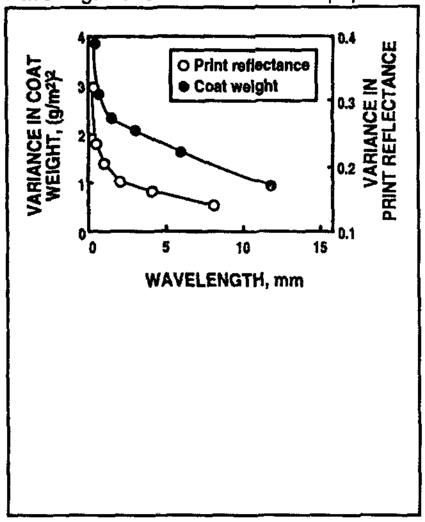
The ratio of variance in surface profile of the coated paper to that of the base paper beneath the coating layer, V_{cp}/kV_{bp}, is a direct measure of the coating mass distribution, provided that the density of the coating layer is constant. If this ratio is equal to unity, the coating layer is uniform in thickness and follows the contour of the base paper surface. The more it deviates from unity, the more uneven is the coating layer.

The variances in surface profile for the coated paper, V_{cp}, and the base paper, V_{bp}, are known. During the

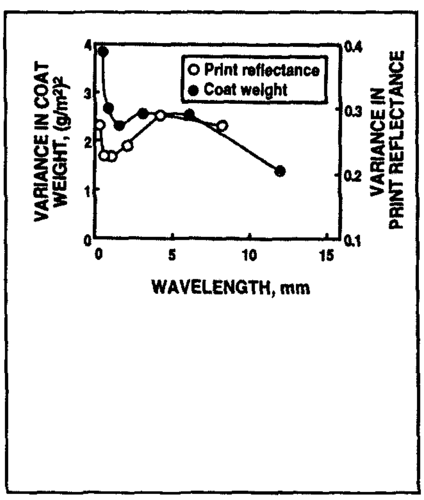
8. Variance in print reflectance of the offset print as a function of wavelength for precalendered and uncalendered base papers



9. Variance in print reflectance of the offset print and in coat weight as functions of wavelength for uncalendered base paper



10. Variance in print reflectance of the offset print and in coat weight as functions of wavelength for precalendered base paper



coating operation, the variance in surface profile of the base paper increases when it is exposed to the water in the coating color (*13-17*). If this variance increases k times, the variance in surface profile of the base paper under the coating layer can be written kV_{bp}.

The ratio of the variance in surface profile of the coated paper to that of the base paper under the coating layer, V_{cp}/kV_{bp}, is indirectly given by the variance in coat weight and decreases when it increases. From Fig. 4, it can be concluded that V_{cp}/kV_{bp} was greater for the uncalendered base paper than for the precalendered:

$$(V_{cp}/kV_{bp})_{uncal} > (V_{cp}/kV_{bp})_{precal} \quad (1)$$

In **Fig. 6**, the ratio V_{cp}/V_{bp} is plotted against the mean value of the wavelength interval. This figure shows that $V_{cp}/V_{bp} < 1$ for both base papers and that V_{cp}/V_{bp} was smaller for the uncalendered base paper.

$$(V_{cp}/V_{bp})_{uncal} < (V_{cp}/V_{bp})_{precal} \quad (2)$$

In order for Eqs. 1 and 2 to be valid simultaneously, it can be concluded that k for the precalendered base paper must be larger than for the uncalendered. This means that the increase of the variance in surface profile in connection with coating was greater for the precalendered base paper. Further, the fact that the coating layer was most unevenly distributed at the fiber floc level indicates that the fiber flocs expanded when the precalendered paper was coated.

Thickness. When paper is coated, its thickness increases because (a) material is added to the surface of the base paper and (b) the base paper picks up water and expands (*16*). The increase in sheet thickness when the first side was coated is shown in **Fig. 7**. The results suggest that the increase in thickness of the precalendered base paper was approximately twice that of the uncalendered paper, regardless of which side (felt side or wire side) is coated first.

The coat weight was the same for both papers, so the increase in thickness from the added material can be assumed to be the same for both base papers. The greater increase in the thickness of the precalendered base paper thus can be explained by the fact that it expanded more than the uncalendered base paper when it was exposed to water. This result is consistent with the greater relative increase in the variance in surface profile under the coating layer for the precalendered paper.

Mottled offset print. The degree of mottling is depicted in **Fig. 8**, which shows the variance in print reflectance for both base papers. The variance in print reflectance was highest for the coated precalendered base paper, indicating that the offset print was the most mottled on this paper. This is in agreement with the subjective impression of the print mottle.

The importance of an evenly distributed coating layer is illustrated in **Figs. 9 and 10**. Each of these figures presents the combined results of Fig. 4 (variance in coat weight) and Fig. 8 (variance in print reflectance) for a given type of base paper. In both cases, the curves for the variances in print reflectance and coat weight have the same shape. This indicates a strong association between unevenness in print reflectance and unevenness in coat weight.

The shapes of the curves for the two base papers were different. For the uncalendered base paper, the variance decreased continuously with increasing wavelength. For the precalendered base paper, on the other hand, the variance passed through a maximum within a wavelength range of about 5 mm. This wavelength range corresponds to the size of the fiber flocs in the base paper. The fiber flocs, in turn, presumably underwent the greatest expansion when the precalendered paper was exposed to water. These results suggest a chain of causes for the mottle in the offset print.

Summary and discussion

The results presented in this report show that:

1. Precalendering predominantly compressed the fiber flocs in the base paper.
2. Fiber flocs expand when the base paper comes into contact with the water in the coating color. Expansion of fiber flocs was greater in the precalendered base paper.

3. Expansion of the base paper beneath the coating layer affected both the distribution of coating mass and the mottle in the print. The coating layer was more unevenly distributed and the print more mottled on the precalendered base paper.
4. The curve describing the frequency distribution for variance of coating mass distribution had the same shape as the frequency-distribution curve for variance in print mottle, indicating a strong association between print mottle and coating unevenness.
5. Uneven distribution of coating mass was associated with uneven distribution of binder in the coating surface.

One important question that this work does not address is whether the fiber flocs expand before or after the blade. If the fiber flocs expand after the blade, then the mass of the coating layer is redistributed during its process of consolidation.

In another work that involved blade coating of three different types of base paper in a pilot coater, it was concluded that the coating layer was more evenly distributed when it was air dried at higher evaporation rates in the hot-air dryer (*12*). Since the coating layers on the base paper must have been equally distributed at the moment of forming under the blade tip, this suggests that the mass of the coating layer may be redistributed during its consolidation process. It is probable that the expansion of the fiber flocs, which affects the coating mass distribution, also takes place after the blade and contributes to a redistribution of the mass of the coating layer.

When the base paper is exposed to water during the coating process, its surface beneath the coating layer becomes rougher. Simultaneously its real area also increases. The coating layer must stretch during its consolidation phase to accommodate the larger surface area. The coating layer encounters maximum stretch and is thus thinnest over the fiber flocs, which expand more than the other parts of the sheet. Hence, a coating layer that is uniform at the moment when it is formed under the blade tip might become uneven in response to the expansion of fiber flocs in the base paper. This phenomenon might be interpreted as a redistribution of the coating mass.

The increase in the surface area of the base paper also may lead to a real redistribution of the coating mass. In this case, the surface tension redistributes the coating color from areas of the coating surface that have expanded more to areas that have expanded less (*26*). The difference between this mechanism and the "stretching mechanism" is that stretching also induces a structural unevenness into the coating layer.□

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