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# Print Mottle : Causes and Solutions from Paper Coating Industry Perspective

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## ABSTRACT

The principal reasons for applying a pigment coating to paper are to improve appearance and printability. The pigment coating provides a surface that is more uniform and more receptive to printing ink than are the uncoated fibers and, in turn, both facilitates the printing process and enhances the graphic reproduction. The improvement in print quality is readily apparent, especially in image areas or when multiple colors are involved. Although pigment coating of paper is to improve the printability, coated paper is not completely free from printing defects. Actually there are a number printing defects that are observed only with the coated papers. Among the printing defects that are commonly observed for coated papers, print mottle during multi-color offset printing is one of the most concerned defects, and it appears not only on solid tone area but also half dot print area. There are four main causes of print mottle ranging from printing inks, dampening solution, paper, and printing press or its operation. These indicates that almost every factors associated with lithographic printing can cause print mottle. Among these variation of paper quality influences most significantly on print mottle problems in multicolor offset printing, and this indicates that paper is most often to be blamed for its product deficiency as far as print mottle problems are concerned. Furthermore, most of the print mottle problems associated with paper is observed when coated papers are printed. Uncoated papers rarely show mottling problems. This indicates that print mottle is the most serious quality problems of coated paper products. Overcoming the print mottle is becoming more difficult because the operating speeds of coating and printing machines are increasing, coating weights are decreasing, and the demands on high-quality printing are increasing.

Print mottle in offset printing is caused by (a) nonuniform back trap of ink caused by a nonuniform rate of ink drying, referred as “back trap mottle, and (b) nonuniform absorption of the dampening solution. Furthermore, both forms of print mottle have some relationship to the structure of the coated layer. The surest way of eliminating ink mottling is to eliminate unevenness in the base paper. Coating solutions, often easier to put into practice, should, however, be considered. In this paper the principal factors influencing print mottle of coated papers will be discussed. Especially the importance of base paper roughness, binder migration, even consolidation of coating layers, control of the drying rate, types of binders, etc. will be described.

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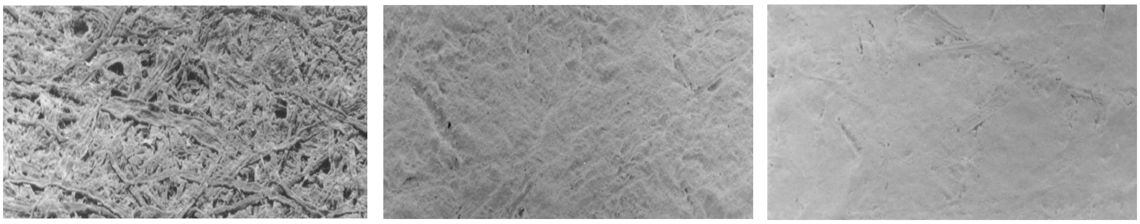
# 1. Introduction

SEM photos in Fig. 1 shows that the rough, porous and irregular surface of base paper is filled with small pigments and binders and changed to have smooth, less porous and more uniform surface after coating. This change improves the appearance of the paper and this is one of the main objectives of paper coating. The principal reasons for applying a pigment coating to paper are to improve appearance and printability. The pigment coating provides a surface that is more uniform and more receptive to printing ink than are the uncoated fibers and, in turn, both facilitates the printing process and enhances the graphic reproduction. The improvement in print quality is readily apparent, especially in image areas or when multiple colors are involved.

The mass distribution within the coating layer is a key parameter determining many properties that-alone or in combination with one another. The mass distribution of the coating layer is determined by a complicated interaction of several factors. However, the conditions during formation of the coating layer seem to be preeminent. These conditions are determined largely by the method used to apply coating. There are three major processes that are being

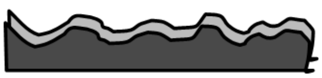


Base paper: w`free 80 uncalendered calendered

Coat weight: 12 g/m$^2$

**Fig. 1. SEM photomicrographs of woodfree base paper, and coated paper before and after calendaring.**

**Table 1. Coating process and structure**

| Methods | Structure | Remarks |
|---|---|---|
| Blade |  | Smooth surface (streaks potential)<br>High surface gloss, and printing gloss<br>Good printing performance |
| Rod |  | In the middle between Blade and Air Knife |
| Air Knife |  | Rough surface, good productivity<br>Uniform coating (contoured)<br>Misting |

used in pigment coating for paper (Table 1). Blade coating is the most widely used coating process today, and this allows us to produce smooth surface for printing in sacrifice of the thickness uniformity of coating layers. And the variation of coating thickness frequently causes printing problems (1).

Although pigment coating of paper is to improve the printability, coated paper is not completely free from printing defects. Actually there are a number printing defects that are observed only with the coated papers. Among the printing defects that are commonly observed for coated papers, print mottle during multi-color offset printing is one of the most concerned defects.

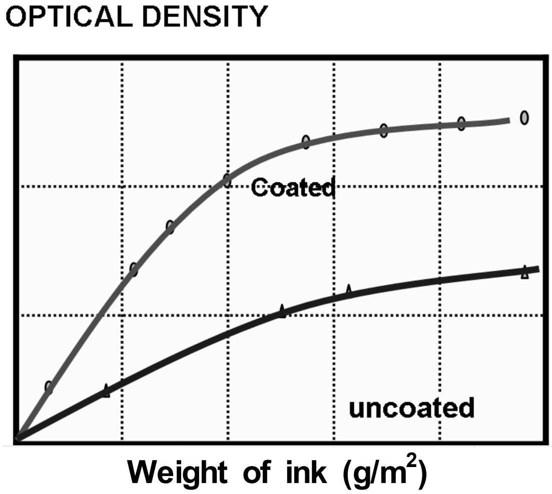


**Fig. 2. Change of optical density and printing ink deposit.**

## 2. Coated paper and print mottle

Print mottle has been defined by many researchers. Fetsko (2) defined print mottle as nonuniform appearance of a solid tone area with sufficient ink covering. Nonuniform distribution of the printing ink which gives an irregular pattern in the print, is often in the form of an orange-peel effect and particularly visible in solid tone area (3). Print mottle that is commonly observed when printing coated papers on multi-color offset printing press appears not only on solid tone area but also half dot print area.

There are four main causes of print mottle ranging from printing inks, dampening solution, paper, and printing press or its operation. These indicates that almost every factors associated with lithographic printing can cause print mottle. If the print mottle is due to inks, dampening solutions or printing process, the papermakers cannot be blamed. Even though the print mottle did not derived from these non paper defects, papermakers still need to clarify that the problem is not associated with paper quality problems. Among the main causes of print mottle paper causes about 75% of all the print mottle problems. Ink/dampening solution and printing press only causes 9% and 16% of print mottles, respectively, indicating that papermakers are most often to be blamed for their product deficiency as far as print mottle problems are concerned. Furthermore, 98% of all the print mottle problems associated with paper are observed when coated papers are printed. Uncoated papers rarely show mottling problems. This indicates that print mottle is the most serious quality problems of coated paper products. The reason why the coated paper tends to have more mottling problems than uncoated papers can be found in Fig. 2 (3).

The optical density of printed area increases with ink weight transferred to paper substrates. It also influenced by the type of papers. Coated papers tend to show higher optical density than uncoated papers when the same weight of ink was applied. If the paper is not coated, its macroporous structure prevents proper settling of ink components and some of the pigments and resin penetrate the paper immediately with the solvent, under the pressure of blanket. With coated papers, on the contrary, macroporosity is limited and replaced by microporosity. This allows effective filtering which immobilizes the ink, leaving the resin embedded pigments on the surface of coating thus gives higher optical print density. The transfer curves of inks can easily be plotted in the laboratory using an IGT press to print paper and by weighing the inking disk. As shown in this slide, slight variations of ink transfer to the coated paper would cause significantly larger variation in print optical density, and this can cause mottled appearance of printed image areas.

# 3. Print mottle mechanisms in offset printing

Print mottle in offset printing is caused by (a) nonuniform back trap of ink caused by a nonuniform rate of ink drying, referred as “back trap mottle” and (b) nonuniform absorption of the dampening solution (4). Furthermore, both forms of print mottle have some relationship to the structure of the coated layer.

Fig. 3 shows the mechanism of back trap mottle. To simplify the model, we will restrict ourselves to the travel of the sheet between two blankets. This model can then be easily enlarged to four printing stations. During transfer between the two stations, the ink film which remained free on the coated surface increases in viscosity as the solvent filters through the already settled resin and pigment layer, and through the micropores of the coating. This establishing concentration gradient of the solvent in the ink is equivalent to increasing the quantity of ink immobilized.

Bearing in mind that the ink film which remains free splits roughly in a 50-50 proportion, the quantity of ink immobilized at each run can be calculated from the difference. An examination of sheets of paper of different porosities clearly shows the change in the amount of ink immobilized according to time.

When the sheet of paper, freshly printed at the first printing station, passes under the following station, the film of ink already on the paper may be partly retransferred to the blanket of the second station This retransfer involves only the portion of the ink film which is still free, as the ink immobilized by microrooughness and by filtration now forms part of the paper. Once balance is attained, after a certain number of sheets have been printed after the start of the run, retransfer of ink from the paper to the blanket should no longer occur, as all the blankets are also covered with a film of ink from the previous printing stations, unless factors of imbalance intervene.

This factor of imbalance may be uneven ink absorption by the paper, which causes irregular distribution of the quantity of immobilized ink when the sheet is about to pass under the second printing station. Retransfer of ink to the second blanket is therefore irregular. The thinly-ink coated areas of the blanket, which coincide with areas of the paper with a thick film of free ink, result in greater retransfer than in other area (Fig. 4).

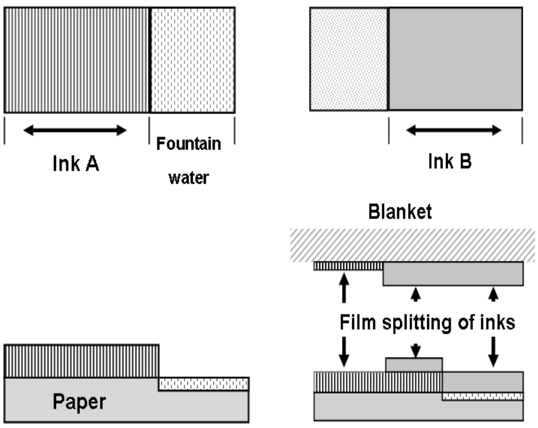



**Fig. 3. Mechanism of back trap mottle**

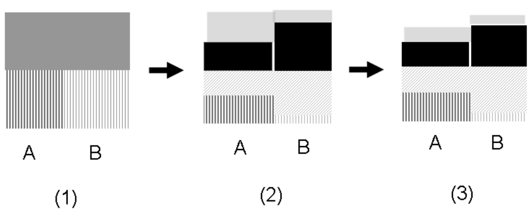



**Fig. 4. Back trap mottle mechanism. More porous coating layer (B) causes quick immobilization of printing ink, and less back tapping than less porous coating (A).**

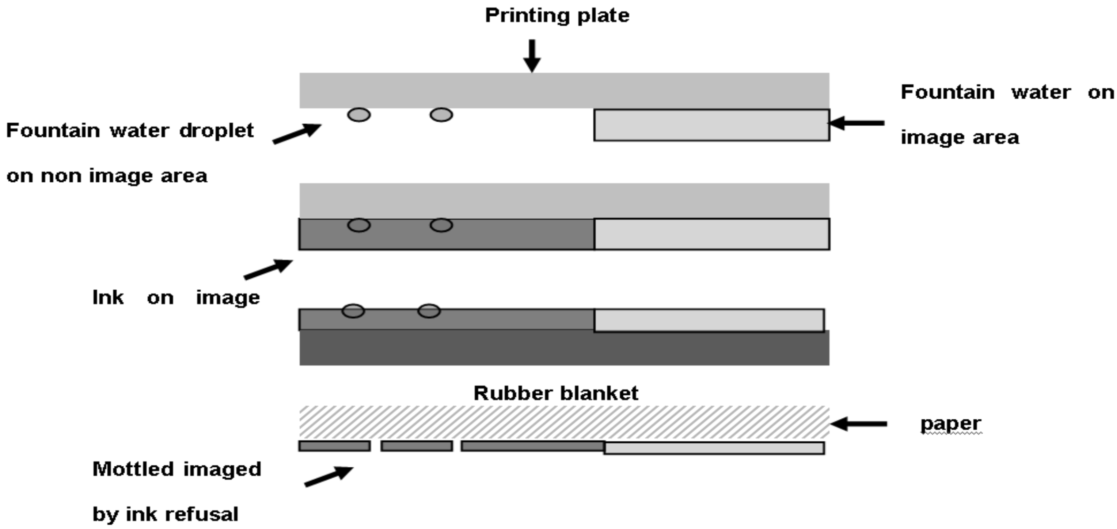



**Fig. 5. Fountain water mottle mechanism.**

To appreciate the role of fountain solution, it is important to realize that a critical phase in the press operation. In addition to full wetting of the nonimage areas, tiny drops of fountain solution are deposited onto the printing areas, without being emulsified. Subsequently these are covered by the ink film at the inking station. They can be thought to act as film splitting aids at the point of transfer to the blanket. The result is that in addition to the emulsified fraction, some fountain solution is present in the form of droplets at the very surface of the ink film. In the case of deficient water absorption by the paper or the coating, this leads to refusal effects (Fig. 5).

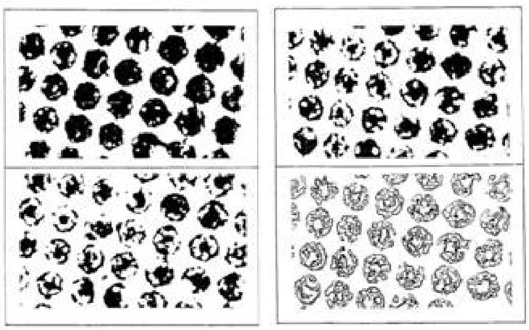



**Fig. 6. Two sets of half tone dots with mottled appearance due to fountain water refusal (left) and back trap (right) mottle.**

Fig. 6 shows two pictures are half tone dots with mottled appearance. But the causes of the mottle are quite different. One can see some difference in print density. For papers on the printed black half tone dots, there are some white areas (light) and some black areas (dark) characterizing areas with more or less mottle. We can even distinguish slightly different areas on paper on the left. The center of the dots are colored, but the outer edges are not well defined. The mottled dot is shaped like a rosette, which is characteristic of the mottling by ink refusal. The ink can not be properly transferred onto the areas that were previously wetted in the first offset unit, producing mottling as a result of ink refusal. Another sets of half tone dots of the light (mottled) and dark areas are shown on the right. In this case print mottle appeared as density variation. And this mottle is a result of irregular back trap of printing ink (5).

## 4. Causes of print mottle

Print mottle is defined as a macroscopic nonuniformity of the print density caused microscopically by either optical density variation of the individual print dots or by variation in an individual print dot area. And it is well known that this problem derives mostly from the irregular quality of coated papers. To investigate what quality variations of coated papers caused the print mottle, area profiles of the print dot area (measured as the percentage of dot area on samples 1 mm X 1 mm) for mottled sample were determined and correlated with the chemical composition at the coated surface. Line profiles of the chemical composition were obtained by scanning the coated paper surface with ESCA. The coefficients of variation for the binder:pigment ratio ranked in this order: Sample A<Sample B<Sample C (6). This order of variation in binder ratio agrees well with that of print mottle. This result gives evidence of a strong relationship between print mottle and the binder distrbution at the surface of the coated paper (Fig. 7).

An approach was taken by Whalen Shaw (7) to unequivocally relate the effect of latex concentration to mottle. He found that light and dark areas constituting mottle could be separately removed and analyzed. This approach is both simple and provides certainty that the material being analyzed is related to either a light or dark area. The binder content of the area low in print density (light blue) is analyzed, and then compared with the binder content in the dark area (dark blue) to find the relationship between binder content and mottle. Ten light blue areas and ten dark blue areas were removed and osmium stained. The surface binder content beneath the ink on no mottle paper was also measured. The dark blue areas in the mottled paper were visually equal in ink density to the no mottle paper. Thus, dark blue areas in the mottle paper are regarded as areas which print satisfactorily. The correlation between the incidence of high localized latex concentration and lack of ink density due to back trap is established (Table 2). Although this cause and effect relationship is quite probable, it cannot be stated that differential surface latex concentration is the only cause in this case of back trap mottle.

To examine the relationship among differential surface latex concentration, the underlying coating thickness distribution, and raw stock roughness within

**Table 2. Surface latex concentration in mottled area**

| | Mottled area | | No mottle |
|---|---|---|---|
| | Light blue | Dark blue | |
| Surface latex concentration | 3884 | 3681 | 3615 |
| CV (%) | 7.2 | 6.8 | 3.8 |

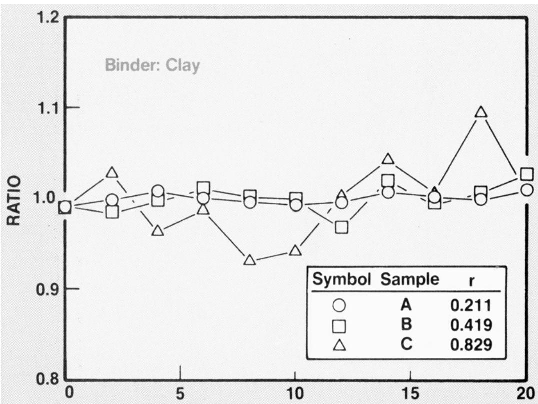



**Fig. 7. Coated papers with high variation in binder/pigment ratio (sample C) showed print mottle.**

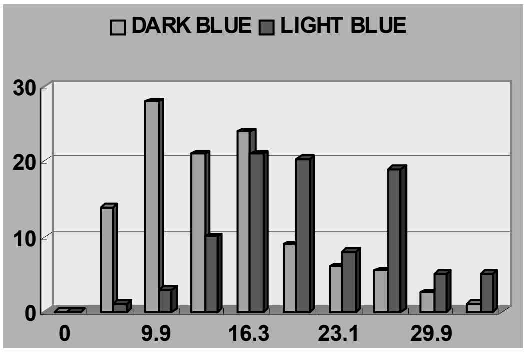



**Fig. 8. Coating thickness distribution for dark and light blue areas.**

the light and dark blue areas of mottle, image analysis of cross sections viewed by SEM was used. Results shown in Fig. 8 show that a significantly greater number of heavy coat weight areas are seen under the light blue area (defected area).

Comparison of this data with surface binder concentration demonstrates the following relationships; Areas of low ink density (light blue) are characterized by higher latex level, higher coating thickness, and lower raw stock roughness. Dark blue areas are similar to the no mottle (control) by having lower latex level, lower coating thickness and greater raw stock roughness.

It was found that areas of low ink density had higher surface latex concentration, greater mean coating thickness, and greater mean raw stock roughness. The binder distribution in the coating surface and the mass distribution of the coating layer can be assumed to be positively correlated, since more binder is transported to the coating surface at higher than at lower coat weights (8). We need to understand what caused the variation of binder concentration for coating layers with different thickness.

## 5. Drying and binder migration

Both drying and dewatering cause water to move through the coating solids matrix. A soluble binder such as starch will move with the water. Once its concentration reaches the saturation value by the action of evaporation, the coating will solidify. This process relates to the bonding action of starch and the gelling of starch-bound coatings. Particulate binders such as latex will move by the viscous drag of the water and will be retarded by the frictional drag against the clay platelets. Capillary movement of water can continue, but binder no longer travels with it (9).

Fig. 9 illustrates a wet coating layer. The essential features are illustrated, including the local variation in coating thickness caused by irregularity of the substrate surface. In the absence of evaporation, with

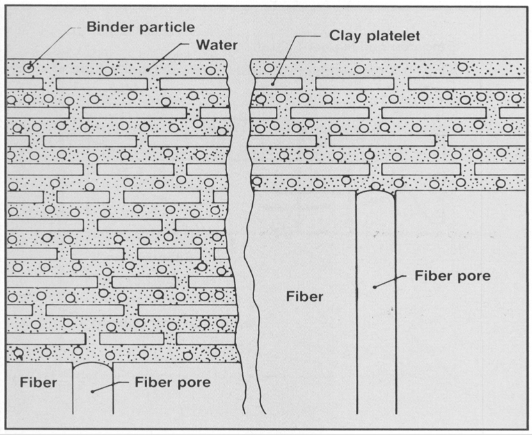



**Fig. 9. Latex bound coating immediately after coating.**

all of the pores in the coating submerged, water will move into the base sheet by capillary action; it will flow through the porous coating from the surface and from the spaces between the platelets. Once the surface water is gone and the water-air interface begins to move into the coating pores, capillary forces will act in opposition to those in the base sheet. Since the coating pores are smaller, the natural behavior of capillary flow will anchor the water-air interface in the pores at the coating surface, which will then be drawn toward the substrate, packing the particles as the water between them is removed. After a period of such dewatering, thin regions of the coating may become

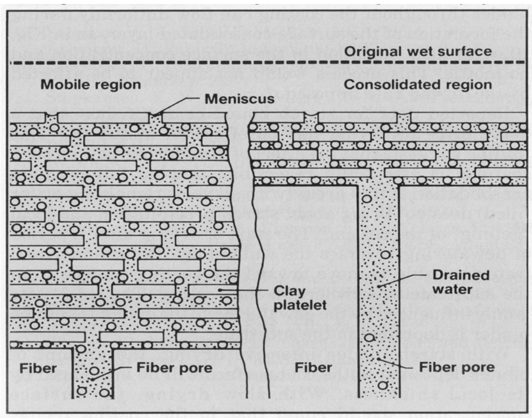



**Fig. 10. Latex bound coating after dewatering without drying.**

fully consolidated while thick regions of the coating is still not consolidated as shown in Fig. 10 (10).

If there are fully consolidated region and mobile region, and the drying rate is maintained at high rate, the binder particles in the mobile region will migrate to the surface, while the binder particles in consolidated region will not migrate to surface. This results in uneven binder distribution on coating surface. To minimize the uneven binder distribution, it is essential to have micro surface roughness in coating base stock. It is required to keep the drying rate at low level when both consolidated and mobile regions are present for producing mottle-free coated papers (Fig. 11) (11, 12).

Drying acts in opposition to dewatering. Evaporation at the coating surface will be replenished by capillary flow, which should always be fast enough to maintain practical evaporation rates. The initial source for this flow will be the free water on the surface. This water will be followed by the water between the pigment particles; consolidation of the coating will accompany its removal. As this free water nears depletion, obeying the concept of small pore preference, the reservoir will shift to the water drained into the base sheet by dewatering. To supply the evaporation at the surface of the coating, water will move along the path of least resistance. Accordingly, its flow from the spaces between the pigment particles should cause preferential consolidation from the surface toward the base sheet.

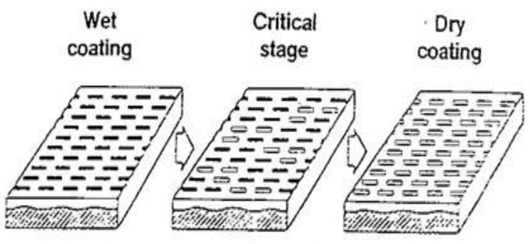



**Fig. 11. Three stages of coating drying. During the critical stage of drying both mobile and consolidated coating layers are present. It is critical to keep the drying rate at low level to reduce binder unevenness on the surface.**

This action would result, early in the drying process, in the formation of a thin, fully consolidated layer at the surface. With a latex binder, this layer would act as a porous skin. Water could continue to pass through to be evaporated at the surface, but binder movement would be prevented. For a starch binder, this layer would have no effect on binder movement (Fig. 12).

When coatings are applied to base paper, the water in coatings penetrates into the base paper during the process from application to drying to make an immobilized layer in the coating layer. When the boundary between the layers that were already immobilized and still not immobilized before heat drying is defined as the immobilization line, water evaporates toward the coating surface from the coating layer over the immobilization line as the result of heat drying.

When the dwell time, from blade tip to the dryer, is longer, greater amounts of water penetrate into the base paper to raise the immobilization line toward the coated paper surface. If the dwell time is long enough the immobilized coating layer will emerge on the surface at those sites with low coat weight. Eventually, two different types of coating layer surface should be formed, one produced by water penetration and the other produced by heat drying.

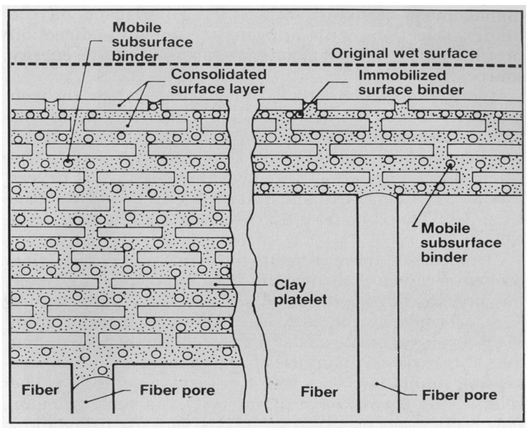



**Fig. 12. Latex bound coating after drying without dewatering.**

# 6. Some solutions

The surest way of eliminating ink mottling is to eliminate unevenness in the base paper. Coating solutions, often easier to put into practice, should however be considered. And this can be achieved in two major ways; By increasing the microroughness of the surface of the paper (12). This is the case of papers coated with fourmula with high calcium carbonate content (3). This solution may, however, involve other disadvantages such as abrasiveness of the coating, low gloss of the ink, etc. By increasing the porosity of the paper. This can be done by adjusting the formulation, in particular as regards the binders to obtain better porosity. This can be achieved by using a latex which gives high porosity particularly as regards the ink solvents (13, 14). It is also possible to adapt the soluble binder by replacing starch by casein or, even better, by polyvinly alcohol.

It is also essential to keep the drying rate under control in the early stage of drying. If there is no soluble binders like starches binder level on the whole surface can be kept at a certain level when one dries the coating at high rate, and keep the time to dryer as short as possible. Also binder selection is important for getting less printing ink density variation of coating layers with different coat weights.

# 7. Conclusion

Pigment coating provides a surface that is more uniform and more receptive to printing ink than are the uncoated fibers and facilitates the printing process and enhances the graphic reproduction. Although pigment coating of paper is to improve the printability, coated paper shows diverse printing defects. Print mottle during multi-color offset printing is the most serious quality problems of coated paper products. Print mottle in offset printing is caused by (a) nonuniform back trap of ink caused by a nonuniform rate of ink drying, referred as “back trap mottle,; and (b) nonuniform absorption of the dampening solution. In this paper the principal factors influencing print mottle of coated papers was discussed. Especially base paper roughness, binder migration, even consolidation of coating layers, control of the drying rate, types of binders, etc. are important factors for producing quality coated papers without mottling.

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