COATER RUNNABILITY

# Factors impeding high-speed runnability of blade coaters

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## ABSTRACT

*Blade-coater runnability at high speeds was studied by two groups of European researchers. This report summarizes their findings, which address the problems of blade wear, streaking, skip coating, and stalagmite formation or bleeding at the blade. The principal focus is the parameters contributing to stalagmite formation and bleeding (basestock; coating formulation, solids content, water retention, and rheology; and blade type, geometry, and angle). Stalagmites form when the flow profile in the metering nip is disturbed by fibers dislodged from the web, pigment agglomerates, or blade-tip defects. Basestock quality is an important factor in stalagmite formation and bleeding, but the metering elements are also important. Indeed, stalagmites can form on the coater even when it is run without a base paper. Mills can improve performance by determining the critical solids content at which stalagmites form for a given coating color. An HP capillary viscometer equipped with "miniblades" was useful in characterizing the runnability of coating colors in the laboratory.*

***Application:***

*Focuses on the factors influencing stalagmite formation and bleeding during high-speed coating of lightweight papers.*

IF YOU WANT TO BOOST PRODUCTIVITY on a coater, the choices are simple: Increase the machine speed or run wider webs *(1, 2)*. The highest speeds are achieved on blade coaters, which are devoted almost exclusively to mechanical paper grades. (Blade-coated wood-free papers are still rare, but their numbers are increasing.)

Since 1965, web widths and machine speeds for blade-coated LWC (lightweight coated) grades have nearly tripled, as seen in **Fig. 1**. Each breakthrough in speed has created a new set of problems that had to be solved before the next breakthrough could take place. The mills operating at today's highest speeds are having problems with high-solids coating and LWC grades.

**Figure 2** illustrates the trend toward lower-grammage papers (from LWC to ultraLWC) in Western Europe over the past 20 years. The graphed trends reflect the natural market pressure to maximize the printed area obtained per unit mass of paper *(3, 4)*.

## BLADE PROBLEMS AT HIGH PRODUCTION SPEEDS

There are myriad problems associated with high-speed coating. Existing restrictions in terms of web run, flying splice, or drive control can be largely overcome by mechanical means *(5)*. On the other hand, problems with coating application and metering are far more critical *(5, 6)*. This article addresses the most serious problems arising from high production speeds—blade wear, streaking, skip coating, and most importantly, stalagmite formation and bleeding.

***Blade wear***

Higher production speeds accelerate blade wear because of:

- Larger prestresses and higher line loads
- Lower coat weights
- Increased abrasion of coating pigments
- Extended dry running of blades without coating color.

The accelerated blade wear at high machine speeds is aggravated by abrasive coating pigments, as seen in **Fig. 3**, which shows coating abrasion *(7)* vs. the number of reels that can be coated with the same blade. (Abrasion was measured with Einlehner AT 1000.) Clearly, blade life drops significantly with increasing pigment abrasion. The results also reflect the increase in abrasion as coat weights decrease.

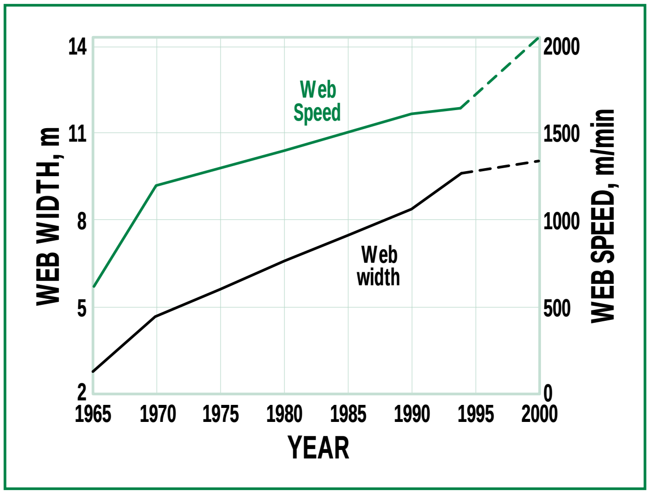
***Streaking***

Streaking is defined as shadow marks, i.e., areas with greater translucence. The shadow marks occur only when stiff blades are used and are most common during application of medium coat weights (10–15 g/m$^2$/side). Specifically, this phenomenon is observed in zones of thicker coatings, where it appears as a streaky pattern in the machine direction *(5)*. If optical brighteners are present in the basestock or the coating color, the streaks can be recognized easily under ultraviolet light.

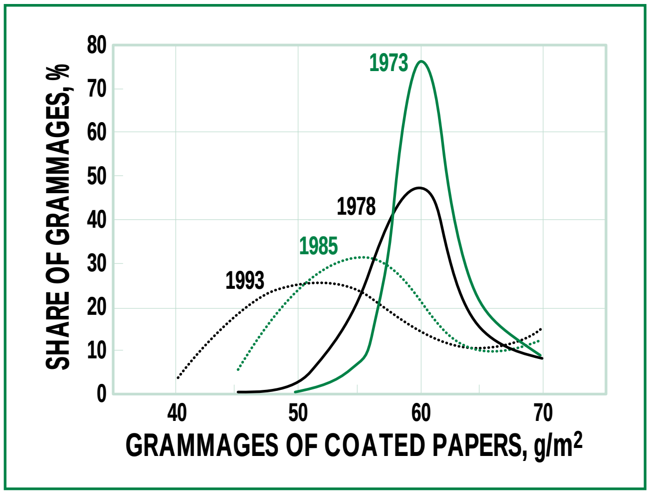
***Skip coating***

In blade coaters equipped with conventional roll applicators, the frequency of skip coating increases at high coater speeds. The SEM (scanning electron microscope) micrograph in **Fig. 4** illustrates the skip-coating phenomenon. This problem is particularly troublesome when coater speeds are raised from 1300–1400 m/min to 1500 m/min and over without changing the coating formulation. Skip coating has several origins:

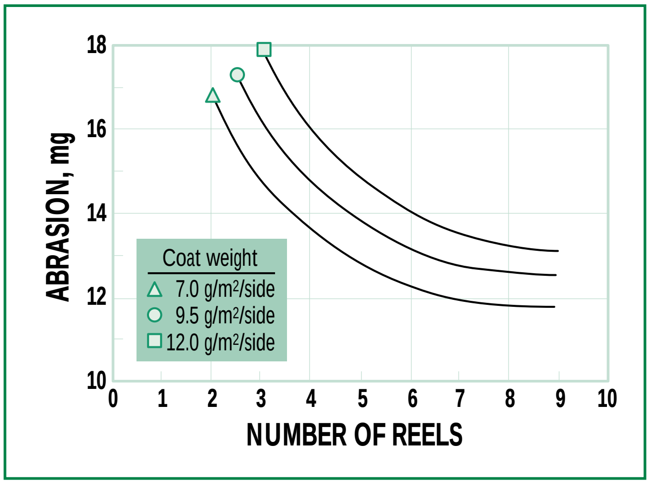
- Trapped air, gas, and foam bubbles in the coating color



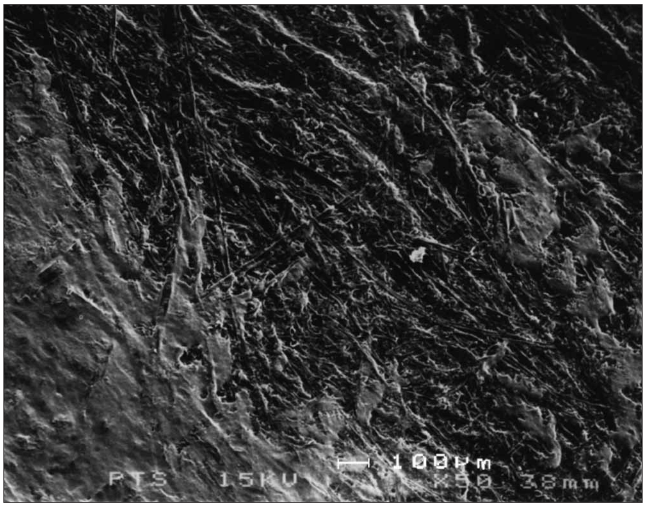

*1. Development of web widths and production speeds for LWC coaters in Western Europe, 1965–2000*




*2. Range of grammage for LWC papers, 1973–1993*




*3. Pigment abrasion vs. number of reels coated with the same blade (LWC basestock, 36 g/m²)*



*4. SEM micrograph of skip coating*

- Insufficient flooding of metering elements
- Insufficient color supply in coating pond
- Unfavorable speed ratio for the applicator roll/backing roll
- Water droplets wetting the sheet ahead of the coater.

Trapped air or gases in the coating-color circuit are generally considered to be the main reason for skip coating. Studies by Li and Burns *(8)* have revealed that, in the case of pond coating, trapped air causes an uneven coat distribution. Aidun *et al. (9)* showed that the volume of trapped air in the pond increases with coater speed.

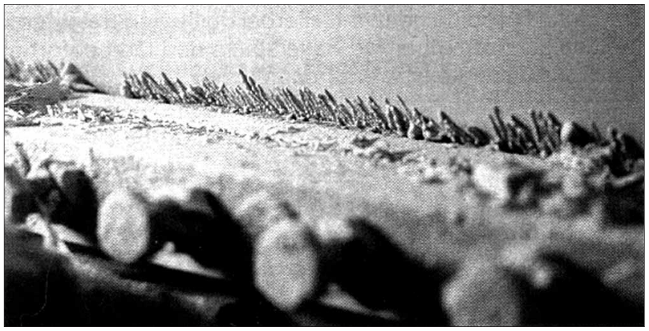
In the case of calcium carbonate-based systems, care must be taken to prevent development of carbon dioxide. This can occur if pH drops below the level at which the dissociation equilibrium of calcium carbonate is influenced (pH≈8.4). Such pH drops could be caused by certain binders or additives in the coating color.

Today, talc-based colors are being used in LWC gravure applications to avoid core bursting. The nonpolarity of the talc, together with the surfactants used for talc dispersion, have the combined effect of enhancing the air content. At elevated coater speeds, this will result in skip coating. **Table I** shows that the air content of a talc-based color far exceeds that of a clay-based color, which can lead to severe problems *(10)*. Addition of 0.05 parts deaerator chemicals had only a modest effect on the air in the coating suspension, reducing it from 19% to 16%.

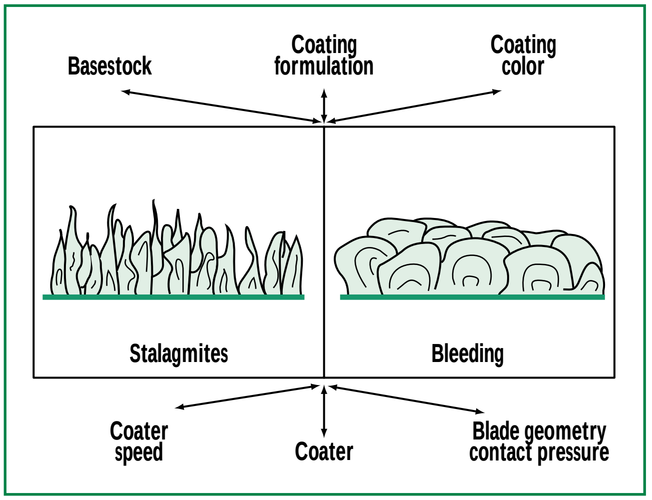
***Bleeding and stalagmites***

***General.*** The discussion of bleeding and stalagmites is based on the findings of the Working Group “Stalagmite formation at the blade” of the ZELLCHEMING Technical Committee for coated papers and coated boards.

The critical speed limit where runnability problems become acute at the blade is 900–1000 m/min. Specifically, color tends to build up to



*5. Stalagmites at blade tip*




*6. Parameters influencing stalagmite formation and bleeding in blade coaters*

different heights on top of the blade, as seen in **Fig. 5**. Depending on its configuration, this phenomenon is described as stalagmites, whiskers, beards, or bleeding in the pertinent literature. Many practitioners and researchers *(11–14)* have commented on the multitude of relevant influential factors, and these are listed in **Fig. 6**. Because these influences are superimposed, it is extremely difficult to track down the exact origins of a runnability problem.

***Coating base.*** The Working Group initially explored the influences of the basestock on bleeding effects. To this end, six different mechanical coating basestocks from five manufacturers were coated on a high-speed pilot coater with an identical color under identical conditions. The details of this trial are reported in the literature *(15)*. **Table II** lists the most important basestock parameters influencing the bleeding phenomena.

Pilot tests and mill-scale trials (in a LWC mill) performed with identical furnishes clearly revealed that a coating basestock produced on a fourdrinier showed a stronger tendency to stalagmite formation than did basestock produced on a twin-wire former. Results of those studies are presented in **Fig. 7**.

Figure 7 depicts stalagmite length as a measure of bleeding for the various grades of coating basestocks. It was found that longer stalagmites were being formed in the topside coating operation. The results in Fig. 7 suggested that the papers showing the longest stalagmites contained the highest share of loosely bonded fibers, fines, and filler agglomerates—contaminants that could be washed from the sheet surface and into the coating color. To verify this, sample base papers were rinsed with water according to a special method developed by PTS. A total of 50 sheets with a surface of 2.53 m² were washed with deionized water in a roll nip. The rinsing fluid was filtered on a cellulose acetate filter with a pore width of 0.45 μm, and the amount of loosely bound particles was measured gravimetrically and by SEM.

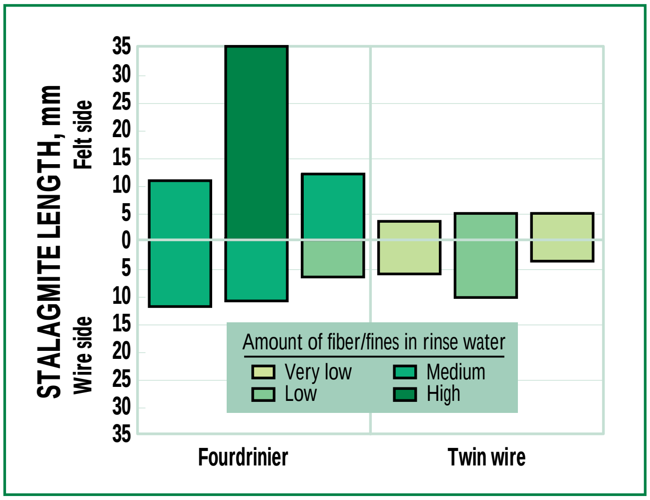
| | FORMULATION | | |
|---|---|---|---|
| | Clay | Talc 1 | Talc 2 |
| Clay | 100 | … | … |
| Talc | … | 100 | 100 |
| Sole binder for clay | 5.0 | … | … |
| Acrylic binder for talc | … | 4.5 | … |
| Sole binder for talc | … | … | 5.0 |
| Solids, % | 58.7 | 58.3 | 56.7 |
| Brookfield viscosity at 100 rpm, mPa·s | 1560 | 1640 | 2540 |
| Air content of coating color, % | 7 | 18 | 19 |

*I. Air content of coating colors containing clay or talc*

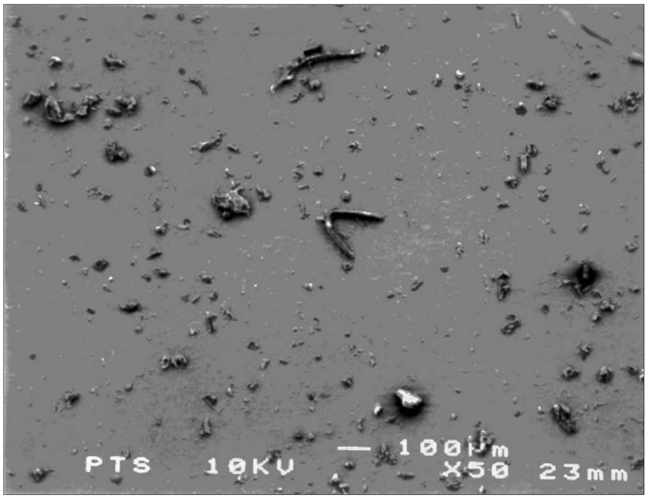
| Parameter | More bleeding | Less bleeding |
|---|---|---|
| Twin-wire former | … | ✓ |
| Surface sizing | … | ✓ |
| Sequence of coat applications * | … | ✓ |
| Fourdrinier top side | ✓ | … |
| Fiber and filler agglomerates washing away | ✓ | … |
| High filler levels | ✓ | … |
| High smoothness (supercalendering, calendering) | ✓ | … |
| High density, low specific volume | ✓ | … |
| High temperatures | ✓ | … |
| Fibers in color | ✓ | … |

* Less bleeding when wire side is coated first

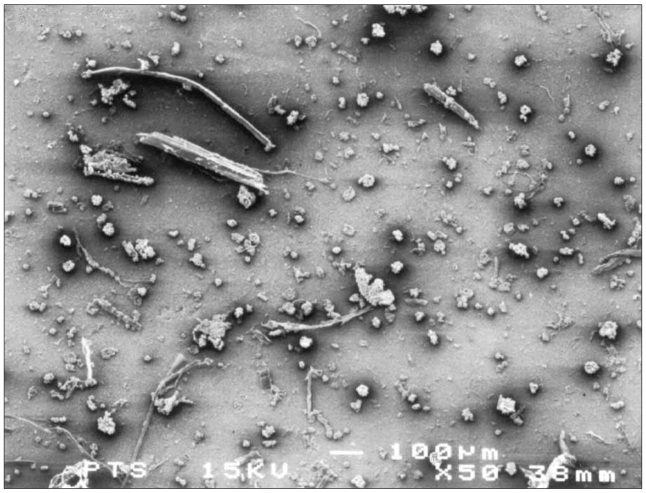
*II. Parameters influencing bleeding—basestock*



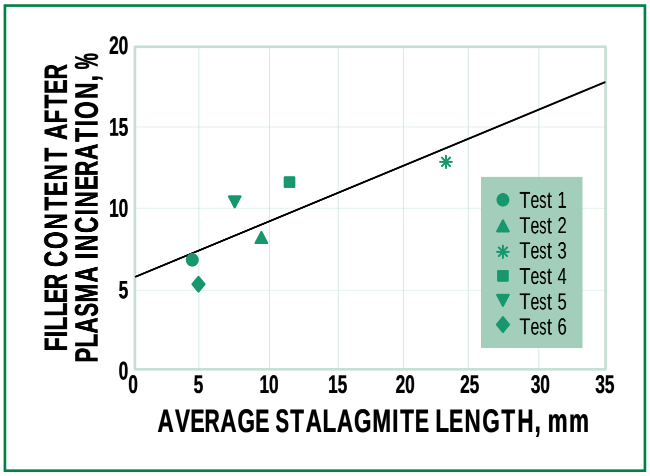

***7. Impact of loose fines and fibers on length of stalagmites***



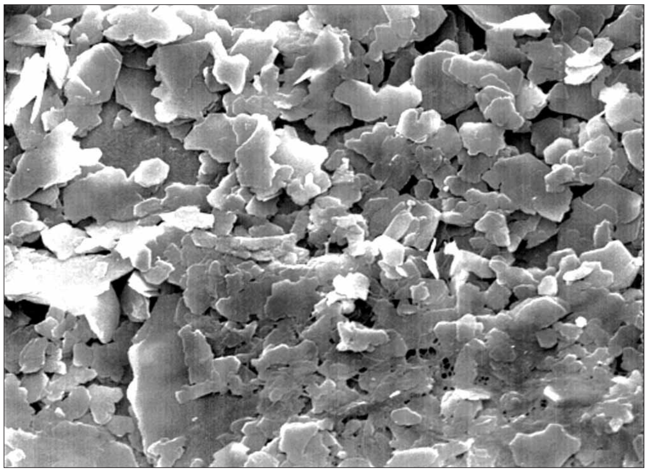

***8. SEM micrograph of particles washed from the top side of a basestock (twin-wire former)***




***9. SEM micrograph of particles washed from the top side of a basestock (fourdrinier machine)***




***10. Impact of basestock filler content on average stalagmite length***



***11. SEM micrograph of coating pigment (English clay) with high aspect ratio***

The SEM micrograph in **Fig. 8** shows particles that were washed away from the top wire side of a paper produced on a twin-wire former. **Figure 9**, in contrast, shows particles washed off the felt side of a fourdrinier paper. Compared with the twin-wire paper, the fourdrinier paper exhibits a far greater number of loosely bonded fiber and filler agglomerates. A very good correlation to stalagmite length was also derived from an analysis of the paper surface using a Fibro 1000 device *(15)*.

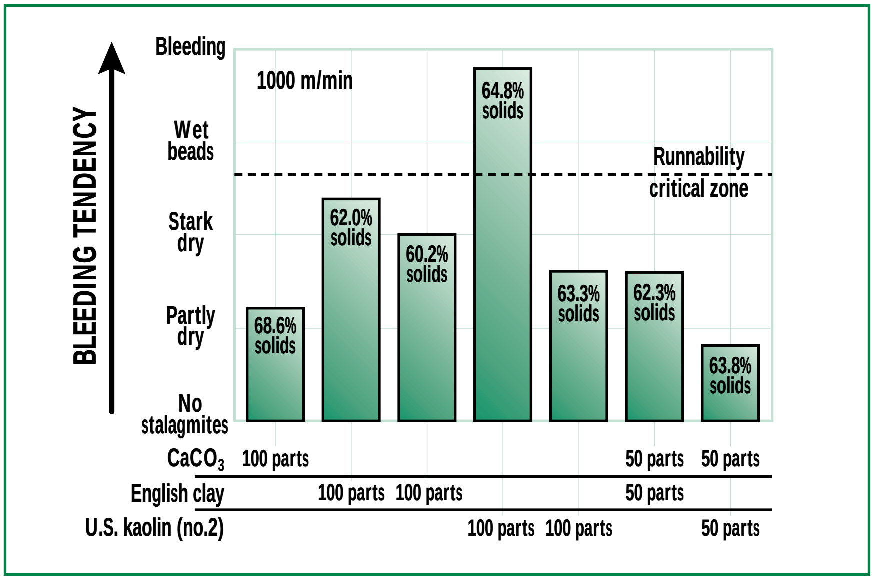
If twin-wire formers are used, fiber fines and fillers are concentrated in the middle of the sheet, so that there are fewer fibers and filler agglomerates capable of being washed away and entering the coating color. Fourdrinier paper are different. As filler levels increase, loosely bonded fillers and fibers tend to accumulate on the felt side of these papers. This material is introduced into the coating color and tends to get caught in the metering nip, thus giving rise to stalagmite formation *(5)*.

As seen in **Fig. 10**, high filler levels increase the tendency toward stalagmite formation. Moreover, high filler levels at the paper surface lead to increased microporosity, thus enlarging the specific surface and accelerating the capillary dewatering of the coating color. Consequently, the so-called critical solids range—where stalagmites begin to form—is reached more quickly.

The available literature *(5, 13)* frequently hints that the principal cause of bleeding is locally excessive dewatering of the coating color between the application zone and the flow break-off edge of the blade. This excessive dewatering results in partial dilatancy and local immobilization of the color. Because higher filler contents increase capillarity, they also contribute to an intensified dewatering in this zone and thus foster stalagmite formation *(15)*.

Basestocks that are calendered or supercalendered in a dry condition are more prone to stalagmite formation *(16)* because the fibers are more easily fragmented and capillary dewatering is accelerated. Surface sizing is eminently suitable for binding loose fiber fragments and filler agglomerates, thus counteracting an excessively rapid capillary dewatering of the coating color.

It was pointed out earlier that the fourdrinier paper showed the longest stalagmites. When this same basestock grade was surface sized with starch before coating, no stalagmites or bleeding were observed. The investigations revealed that stalagmite formation or bleeding occur less frequently when coating the second side of the sheet. This might be explained by the first coat acting as a barrier to fast capillary dewatering. An alternative reason might be that there are simply fewer loosely bonded fibers and filler particles on the sheet when the second-side coating is applied.




***12. Impact of pigments on stalagmite formation and bleeding (coater speed = 1000 m/min)***

| Parameter | More bleeding | Less bleeding |
|---|---|---|
| Coating pigments | | |
| Particle shape (high aspect ratio) | ✓ | … |
| Narrow particle size distribution | ✓ | … |
| Coarse particle fractions | ✓ | … |
| Binders and cobinders | | |
| Synthetic binders [a] | ✓ | ✓ |
| Synthetic binders with high affinity to pigments | … | ✓ |
| Starch use | … | ✓ |
| Excessive starch use | ✓ | … |
| Cobinders [b] | … | ✓ |
| Cobinders of excessive molecular weight | ✓ | … |

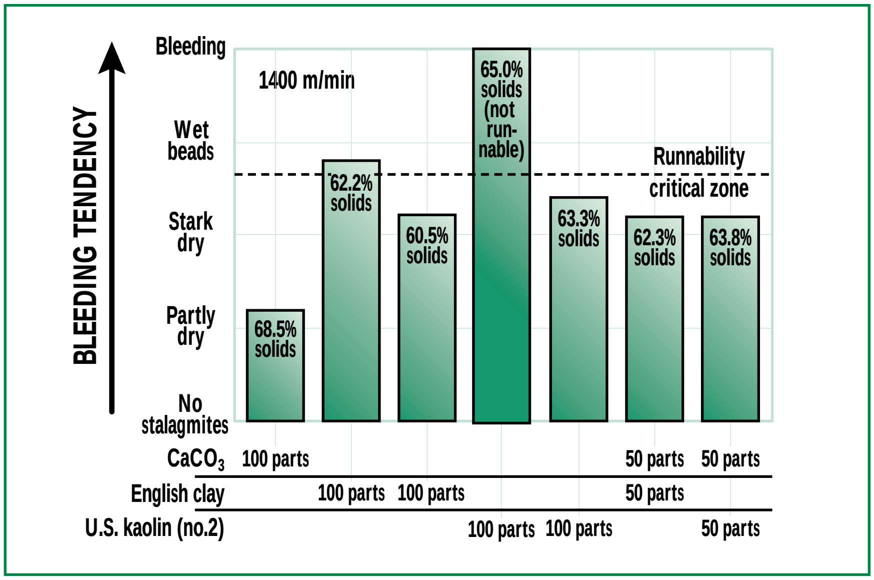
[a] Specific effect depends on coating rheology and water retention
[b] For optimum dosages of synthetic thickeners, carboxymethyl cellulose, guar, polyvinyl alcohol, and others

***III. Parameters influencing bleeding—coating formulation***

***Coating formulation.*** **Table III** lists the coating-formulation parameters that influence stalagmite formation and bleeding. There is general agreement in the literature that the pigment type distinctly impacts these phenomena. Coating pigments of a high aspect ratio, i.e., pigments of a pronounced platey nature (**Fig. 11**), have a stronger bleeding tendency—even in the low-solids range—than pigments with a low aspect ratio or spherical, rhombohedral $CaCO_3$ particles. Additional factors favoring stalagmites and bleeding include a narrow particle size distribution of the coating pigments and coarser pigment fractions *(13, 16, 17)*.

**Figure 12** illustrates the effects of pigments on bleeding. First of all, the pigments were compared individually—and in part at different color solids—for coat weights of 12 g/m$^2$ per side that were applied to 35-g/m$^2$ wood-containing basestock at a coater speed of 1000 m/min.

For the coating color containing U.S. kaolin (lower aspect ratio than English clay), the runnability at 1000 m/min was greatly improved by reducing the solids from 64.8% to 63.3%. This brought the coating color under its critical solids range and well below the critical value at which sta-




*13. Impact of pigments on stalagmite formation and bleeding (coater speed = 1400 m/min)*

| Parameter | More bleeding | Less bleeding |
|---|---|---|
| Slow dewatering | … | ✓ |
| High solids | ✓ | … |
| High coating color temperature | ✓ | … |
| Low water retention | ✓ | … |
| High viscosity | ✓ | … |
| Dilatancy | ✓ | … |
| Presence of fibers | ✓ | … |

*IV. Parameters influencing bleeding—coating colors*

| | COBINDER ADDITIONS | | |
|---|---|---|---|
| | Polyvinyl alcohol (1.5%) | Synthetic thickener (1.5%) | Polyvinyl pyrrolidone (5.5%) |
| Capillary viscometer (at D = $10^6$ $s^{-1}$), mPa·s | 100 | 120 | 140 |
| Water retention (BASF method), s | 31 | 78 | 128 |
| Dewatering after 2 s (clay slab method) | 15.1 | 6.9 | 7.5 |
| Runnability assessment | 1 | 3 | 2 |

* Coating formulation: 70 parts English clay, 30 parts calcium carbonate, and cobinder content as given in table. Solids = 62.5%.

*V. Impact of cobinders on stalagmite formation and bleeding* *

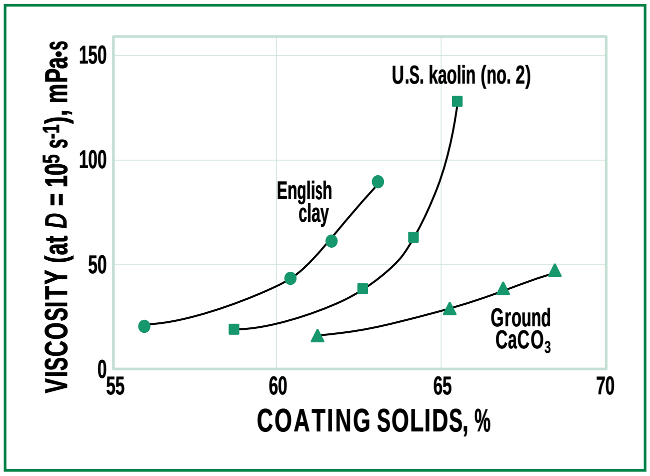
lagmites form. The coating color containing English clay (higher aspect ratio than U.S. clay) showed a runnability at 60.2% solids that was comparable with that of the U.S. kaolin color at 63.3% solids. By comparison, a coating color including ground natural calcium carbonate tended to form semiwet stalagmites at a solids content of 68.6%. When the coater speed was increased to 1400 m/min (**Fig. 13**), the color containing U.S. kaolin reached its runnability limit at a solids level of 65% and showed a pronounced tendency toward stalagmite formation and bleeding.

The impact of synthetic binders on stalagmite formation and bleeding is strongly dependent on their rheology, water retention, and shear stability. Experience shows that synthetic binders with high affinity to pigments exhibiting a high adsorptive capacity at the pigment interfaces are less prone to cause bleeding *(6)*. Low starch levels have a positive influence on stalagmite formation and bleeding, whereas high starch additions—depending on the molecular weight, degree of substitution, etc.—have the opposite effect and tend to worsen the bleeding problem.

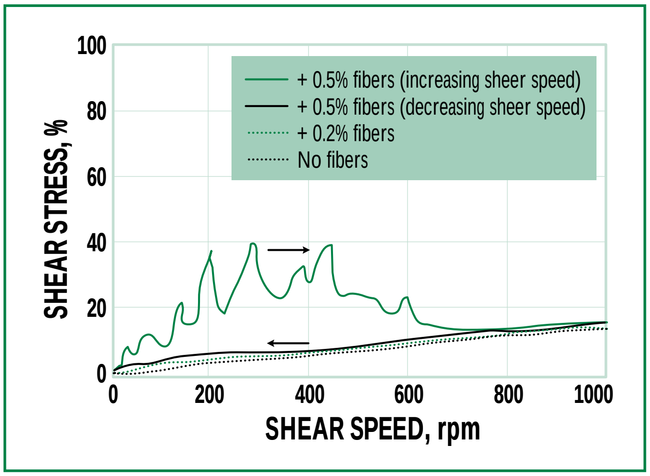
Good runnability characteristics of a coating formulation are decisively dependent upon the cobinders and protective colloids used. For example, if the system is set to a specific water retention, improved runnability and reduced bleeding are achieved with higher shares of low-molecular-weight hydrophilic polymers rather than with lower shares of high-molecular-weight products.

***Coating colors.*** **Table IV** lists the coating-color parameters that influence stalagmite formation and bleeding. The enormous influence of coating solids has been noted previously *(18)*. From both an economic and a quality perspective, coating colors must be applied at the highest practicable solids contents. In actual coating operations, this inevitably leads to critical phases and critical solids. If dewatering initiates very quickly, solids increase beyond the tolerable limit, and contact pressures must be increased to maintain the requisite coat weight.

High temperatures and inadequate water retention are additional factors that can bring the coating suspension within a solids range at which stalagmites start to form in response to excessive dewatering. On the other hand, **Table V** shows that a high water retention alone cannot safely prevent bleeding either. In this case, the coating formulation with the lowest water retention performed best in terms of bleeding. This discrepancy might be




*14. Viscosity vs. solids for different pigment types (data from Eklund and Fors* (19)*)*

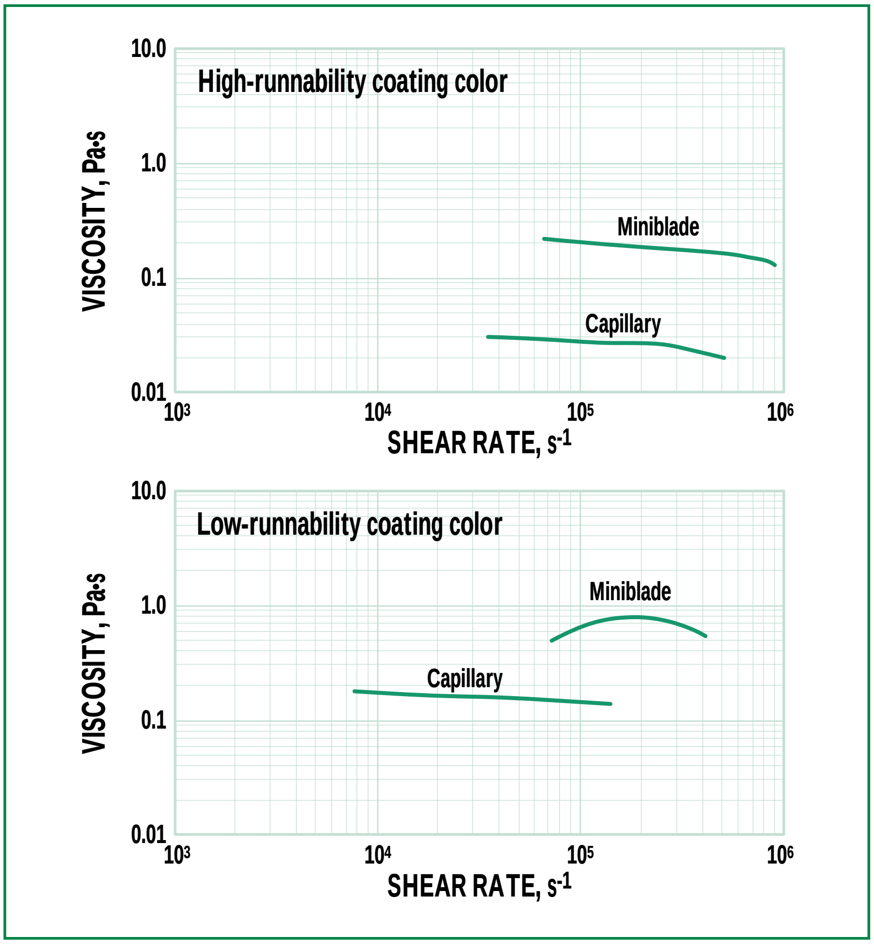



*16. Impact of fiber addition on coating-color rheology*

attributed to the customary method for measuring the water retention, which fails to give meaningful results in the high-shear range.

In **Fig. 14**, viscosities are shown vs. solids for English clay, U.S. kaolin, and $CaCO_3$. This figure confirms the hierarchy of bleeding tendencies: English clay with a high aspect ratio is first, followed by U.S. kaolin with a low aspect ratio, and rhombohedral natural $CaCO_3$ *(19)*. Stalagmite formation can be observed earlier if a platey clay is used.

Of particular significance for bleeding is the rheology of the coating formulation. In this context, two real coating formulations were studied, one that showed good runnability and another that caused severe stalagmite formation. Measurements with a standard HP capillary viscometer (HVA 6) did not reveal any correlation to stalagmites, except for a higher overall viscosity level, as seen in **Fig. 15**. Other tests were made after installing so-called "miniblades" instead of capillaries in this viscometer to better simulate the short shear times as they occur under a blade. The results more clearly indicate the dilatancy of the poorly running coating color.



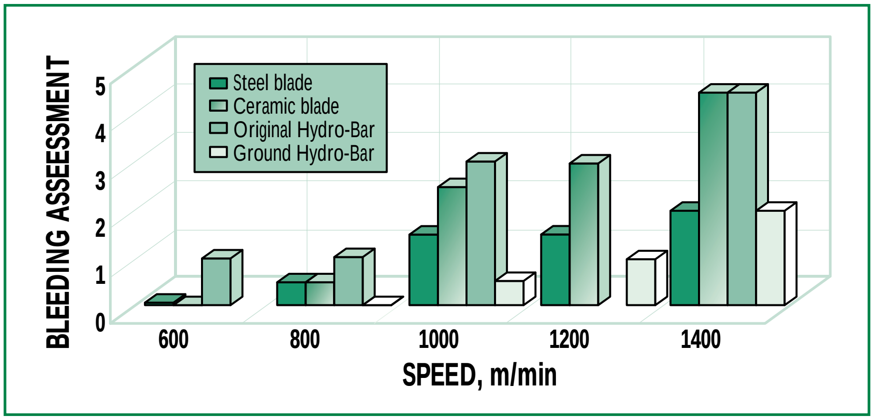

*15. Runnability assessment of high- and low-runnability coating colors with a standard capillary viscometer and a modified viscometer with "miniblades" to simulate short shear times*

Mill studies of stalagmites on the blade showed that they contained high levels of fibers. In hard-dried beards, fiber contents of up to 7% were measured. In light of this observation, fibers were added to the color in the trials *(19)*. Fiber additions of only 0.2% caused a marked increase in stalagmites. However, there was no change in coating rheology at this level of fiber addition, as seen in **Fig. 16**. (Rheology was measured using a Haake HS1 rotational viscometer.) When the fiber content was increased

| Parameter | More bleeding | Less bleeding |
|---|---|---|
| Exact blade geometry (converging blade angle) | ... | ✓ |
| Bent blade | ... | ✓ |
| Influence of metering elements [a] | ✓ | ✓ |
| Increased speeds | ✓ | ... |
| Diverging blade angle (trailing on the edge) | ✓ | ... |
| Extended length of contact zone | ✓ | ... |
| Stiff blade | ✓ | ... |
| Excessive dewatering of the color before final metering [b] | ✓ | ... |
| Local flow disturbances in the metering zone [c] | ✓ | ... |

[a] Specific effect depends on speed
[b] Caused by the basestock, insufficient flooding of applicator roll, or excessive contact pressure of premetering elements
[c] Caused by fibers, agglomerates, or blade defects.

*VI. Parameters influencing bleeding—coater*




***17. Impact of metering elements on bleeding (0 = no bleeding, 5 = maximum bleeding); determined by applying coating color directly to backing roll in the absence of basestock; data from Sommer* (17)**

to 0.5%, the rheology changed (Fig. 16), and there was a corresponding increase in stalagmite formation, as would be expected.

***Coater.*** **Table VI** lists the coater parameters that influence stalagmite formation and bleeding. The previous discussion addressed the effects of basestock, fibers in coating suspensions, and high coater speeds with a changed color rheology. The remainder of the discussion considers the occurrence of bleeding in the absence of a coating basestock. For this purpose, coating trials were conducted on the backing roll without paper. The results are presented in **Fig. 17**.

Additional tests were carried out to demonstrate the influences of the various metering elements and blade geometries. The results in Fig. 17 demonstrate that at higher coater speeds, bleeding also occurs in the absence of a coating basestock. With all blade types, bleeding initiates in the form of wet deposits at speeds around 1000 m/min and increases as the coater speed rises to 1400 m/min *(17)*.

Bleeding was found to be at a maximum with an unbeveled ceramic blade. The results were even worse for the original stationary solid-bar metering device with a radius at the tip (Hydro-Bar, profile R = 0.2 mm at the tip of the metering element). On the other hand, ceramic blades are less prone to wear, which favorably affects the bleeding tendency over protracted periods of operation. Reground Hydro-Bar profiles were found to perform far better in terms of bleeding. Significantly, bevels across the direction of web motion give superior results to bevels in the machine direction.

Whenever the production conditions are characterized by excessively high solids content or dilatancy, bleeding or stalagmite formation will be immediately initiated if a blade with a defective tip geometry is used. The ideal metering geometry is a uniformly converging metering nip with a sharp edge for flow break-off *(5, 14)*. Diverging metering nips, in contrast, tend to cause bleeding even at low coater speeds. It should be added that the performance of the bent blade when new is superior to that of the stiff blade in terms of bleeding.

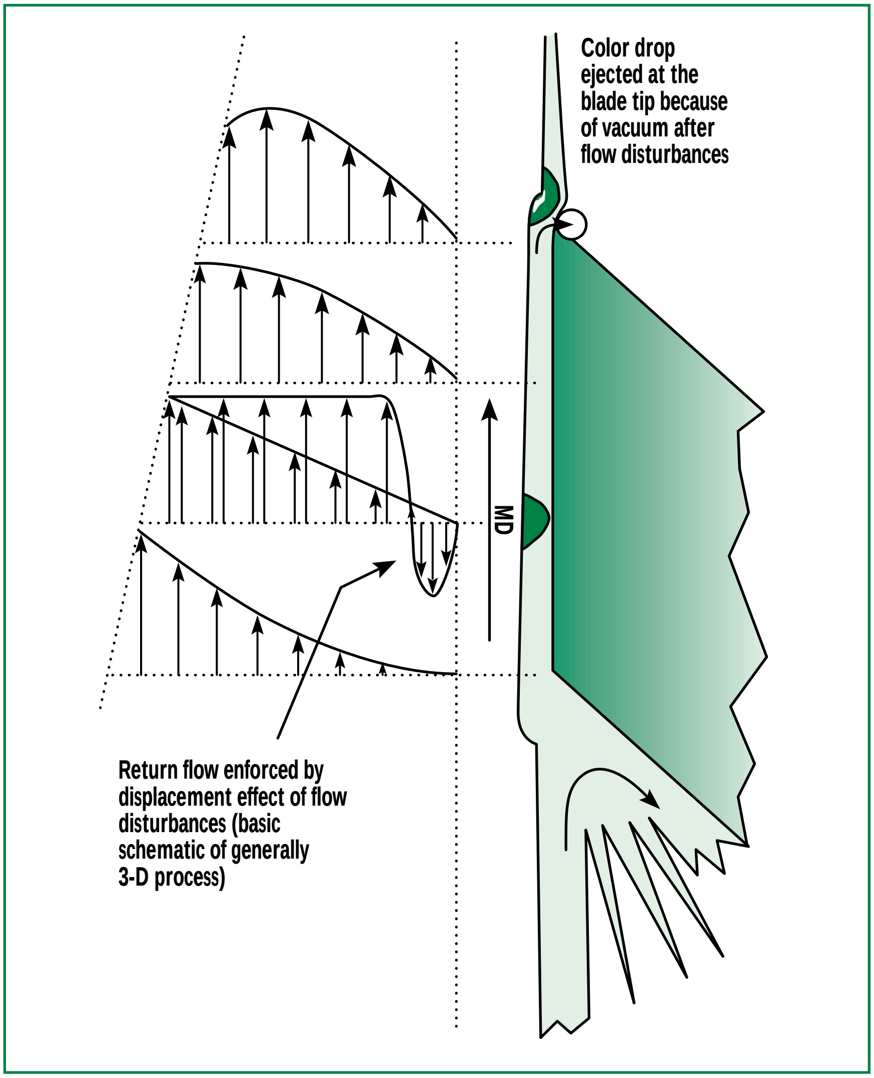
It may happen that the coating suspension is excessively dewatered before being metered onto the paper. This could be caused by the basestock, insufficient flooding of the roll applicator, or excessive contact pressure of premetering elements. In these cases, coating operations will soon lead to critical solids contents of the coating color, at which point the changed rheology will support bleeding and stalagmite formation. Local flow disturbances in the metering zone are bound to cause bleeding or stalagmites, as illustrated in **Fig. 18**.

When paper fibers or pigment and filler agglomerates are caught in the metering nip, the coating color envelops the obstructing material, creating boundary layers with still areas or reverse flows. The droplets that are formed on the blade tip can become the nucleus of bleeding or stalagmites, depending on solids, temperature, etc.

**KEYWORDS**

*Blade coating, blades, bleeding, coated papers, coating, coating color, high velocity, machine components, paper grades, runnability, velocity.*

Similar mechanisms are initiated if the blade tip shows defects like microindentations. **Figure 19** is a SEM micrograph showing the tip of a used stiff blade viewed from the trailing to the leading edge. The scratches and dents in the blade are clearly visible.




*18. Impact of flow disturbances beneath the blade on bleeding; data from Sommer* (17)

## SUMMARY

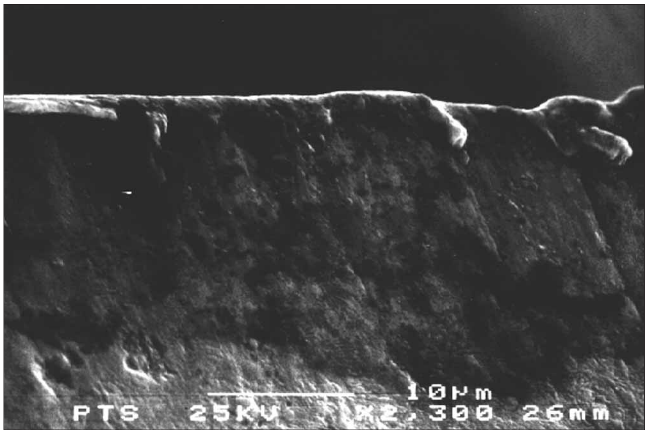

Production failures are becoming increasingly common during high-speed coating of lightweight printing papers. Bleeding at the blade and stalagmite formation are the main impediments to further gains in productivity. Runnability and product quality are dependent on the quality of the basestock, the type and condition of the coating equipment, the coating formulation, and coating characteristics.

Trials conducted on pilot coaters at maximum speeds of 1500 m/min yielded the following results:

- Dry whiskers have a higher fiber content than wet stalagmites.
- Increasing filler levels and basestock densities foster bleeding and stalagmite formation.
- The smoother felt side of fourdrinier papers is more prone to bleeding than the wire side. In contrast, twin-wire-formed papers are less prone to bleeding.
- Coating formulations containing coarse-particled clay with a high aspect ratio and a narrow particle size distribution are more prone to bleeding than are calcium carbonate-based colors.
- Small starch dosages improve runnability, but runnability problems are aggravated if starch additions exceed a certain limit.

Because the parameters influencing bleeding and stalagmite formation are interrelated, favorable runnability characteristics cannot be achieved by optimizing a single parameter. This highlights the need to match coating colors to the basestock and the coating conditions in terms of color solids, formulation, water retention, and rheology.

For the past three years, mills have been installing water-vapor steamers on their coaters. This approach reduces stalagmites or bleeding by helping to clean the blade and by sort of liquefying the immobilized coating color. These systems improve quality and reduce costs by enabling mills to run a wider range of pigments and coating-color systems while reducing production failures. **TJ**


*19. SEM micrograph of blade-tip defects*

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