Operational Limits of Blade Coating on Absorbent Substrates

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<u>Extended Abstract</u>:

High speed blade coating is a common process to apply coatings on webs at high speeds. For example, during the coating of paper, a suspension of pigments and latex at 55-65% solids content is applied to a porous web at speeds of around 10-20 m/s and wet thicknesses of 10-50 μm. There are advantages to operating at high solids and high speeds, but at some limit, defects are generated in the coating layer and material can build up on the blade. The maximum solids for smooth operation is much lower for high aspect ratio pigments, such as platy kaolins, compared to pigments that are more regular in shape. However, these operational limits are not well understood.

One of the initial indications of potential operational issues is blade bleeding or blade deposits. This is a buildup of coating on the back side of the blade and is often called stalagmites, weeps, or whiskers. There are three types of blade buildup. Wet bleeding, which is the slow extrusion of coating, or the formation of a dry stalagmite and lastly a combination of both wet and dry stalagmite growth (Gane *et al.,* 1997). The exact conditions that lead to stalagmite formation are not well characterized. These may be linked with a jamming of particles at the blade tip, the buildup of a filtercake on the paper, or the development of a slip plane at the paper surface (Gane, 1997; Gane *et al.,* 1992). High aspect ratio pigments, narrow particle size distributions, low water retention, high viscosities, high machine speeds and high solids contents are some of the conditions which seem to lead to more stalagmite formation (Weigl and Grossmann, 1997). Also, operating the blade on the heel is known to generate a low pressure region at the blade tip, leading to cavitation and wet ejection of materials (Engström and Rigdahl, 1989).

The maximum coating speed as a function of solids and pigment shape are reported. The absorption properties of the paper, the rheology of the coatings at different solids, and the dewatering properties of the coating are characterized.

Materials and Methods

Two pigments were used in this runnability study; Astra-Glaze (Imerys) and XP01-6100 (Imerys). These pigments have average shape factors of 15 and 90, respectively, as reported by the supplier and are denoted K15 and K90 below. Shape factor is defined in a specific manner by the supplier but can be taken as an average aspect ratio of plate shaped particles. These pigments will be identified based on their aspect ratio or shape factor as either K15 or K90. Slurries of these pigments were prepared using a high shear mixer to ensure sufficient dispersion of the particles. The mass fraction of the slurries was determined by an infrared moisture analyzer (IR-35, Denver Instruments). In this runnability study, no other dispersants, additives or latexes were included in the suspension other than what is already added by the manufacturer except for a small amount of a dye (<1% by weight). This dye helped color the white pigment to aid in the detection of quality issues in the final coating layer. This was done to limit the complexities of the suspension while focusing on the effect that particle aspect ratio has on the interactions with the coating equipment. The viscosity of the pigment suspensions at a shear rate of

10,000 s^{-1} and varying weight fractions was measured using a cup and bob rheometer (Kaltec Hercules Hi-Shear Viscometer) using bob E ad a ramp time of 20 s. The data were fitted to the Mooney equation which relates the viscosity to the volume fraction using two parameters to describe the sample, following a similar method as that outlined in Weeks *et al.* (2016). The viscoelasticity data of the slurries was determined using a Bohlin Gemini II rheometer with a 25 mm parallel plate geometry. An oscillatory test with a frequency sweep between 0.1 and 30 Hz at a constant strain of 0.01 was used. The immobilization solids were determined for each of the pigments by placing a small volume of the slurry onto a porous ceramic disk. Once the wet gloss from the surface of the slurries disappeared, the sample was removed and the solids content determined.

The base sheet used in these tests was a paperboard coated on one side with a basis weight 222 g/m^2. The coated side of the substrate was less permeable and had a smoother surface than the uncoated side. The base paper pore size distribution was characterized by mercury intrusion porosimetry. The porosity of the base sheet was found to be 0.25. The absorption rate of water was determined for each side of the paper by the Bristow wheel tester (Bristow Laboratory Apparatus).

The runnability tests were conducted on the CLC (CLC 6000, Sensor and Simulation Products). The pre-dry and the post-dry settings were kept constant for all trials at 5 and 15 seconds at 50% power, respectively. The coat weight was also held steady at an average of 25 g/m^2 by adjusting the gap setting on the CLC. A small wireless camera (GoPro Hero 3+) was attached to the bottom of the moving carriage. It was used to record any potential operational issues that occurred at the blade exit. The solids concentration of each of the two pigments was varied and the speed at which operational and quality issues begin to appear was determined. The maximum speed where quality issues first were seen in terms of scratches is reported as well as the first observation of blade deposits or spitting of coating. These were often quite similar. More details of the trials and set up are in Weeks (2017).

Results

Figure 1 shows the operational window of the K15 pigment on the uncoated and coated sides of the paperboard. The quality and operational limits are quite similar. As expected, as the solids increase, the maximum operating speed decreases. Also, the coated and uncoated sides of the board have similar results: this indicates that the absorption of fluid by the porous web in this case does not influence the results. Note that the solids level is high (71%) compared to where a typical paper coating is applied (65%); this result may come from the lack of binder in the system.

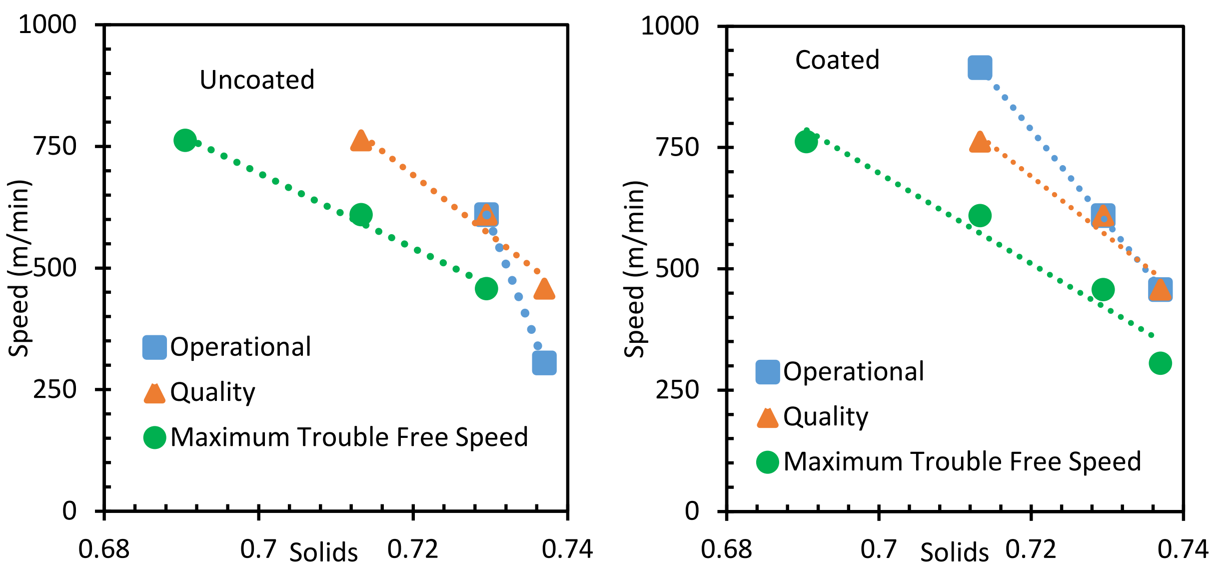

Figure 1. Runnability window developed for K15 on both the uncoated and coated substrates

The results for the K90 pigment is in Figure 2. The trends are the same for the K15 pigment except that the solids range is much lower, around 55% solids. The uncoated side has around 20% lower speed limits than the coated side: this indicates that the absorption of fluid does influence the operating window to some degree.

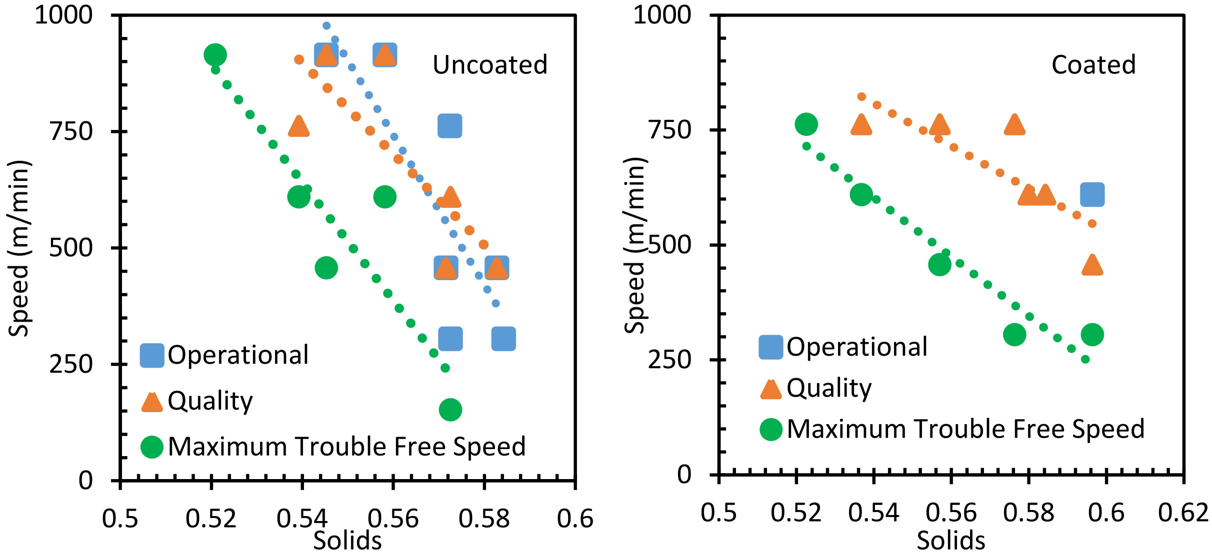

Figure 2. Runnability window developed for K90 on both the uncoated and coated substrates

The viscosity of these pigment slurries at 10,000 1/s at various solids is given in Figure 3. The first impulse, in looking at the results in Figs 1 and 2 is to blame the high viscosity of K90 on the small operating window. However, K90 is able to be coated at a higher viscosity than K15. Note that the viscosity at 55% solids is around 0.3 Pas while it is only 0.06 Pas for K15 at 73% solids. In itself, steady shear viscosity does not predict or relate the operational window.

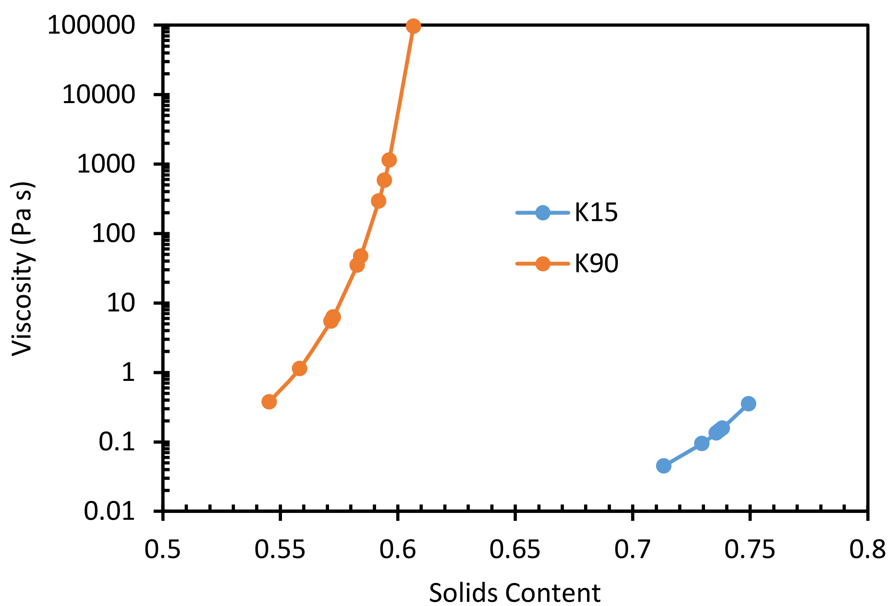

Figure 3. Calculated viscosity (Pa s) from the Mooney equation for K15 and K90 at the solids content used in the runnability studies

A correlation to the complex viscosity of these systems and the operational window was found to be possible (Weeks, 2017). This would make sense in that a rapid response to a shear field is needed for the coating to be able to flow and deform under the blade in a regular way. However, oscillatory type results were difficult because of drying of the suspensions and the time needed to obtain the results.

Figure 4 shows a relationship that seems to have some potential to link the two different pigments. The difference in the immobilization solids, as determined by the porous plate method, and the current solids seems to correlate to the maximum operating speed for both pigments and was given the symbol ΔS. This difference is solids content is a measure of how close to the "locking up" the coating is. If the difference is large, the maximum coating speed can be large. The immobilization solids is a test that can be done even on site and may be able to predict the maximum operating speed. If this correlation holds true for coating that have latex binder or soluble polymers, such as starch, is not known.

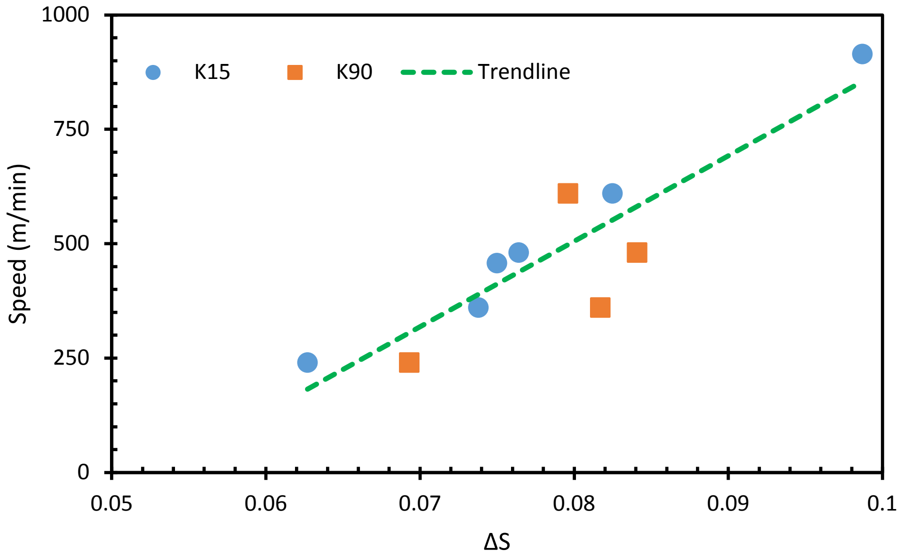

Figure 4. Linear relationship between ΔS and the roll speed at which operational issues appear for both K15 and K90

Visual observations of the defects seem to indicate that the no slip boundary condition at the blade surface is violated, or at least it seems that the coating is extruded from the nip of the blade and paper. Figure 5 shows a spit forming at the blade nip and the ejection of material from a region. It seems like the suspension jams to form a region of fluid that is pushed out from the blade tip, but it is not sheared in the normal manner under the blade. Again, this may be linked to the particles jamming in the blade nip, disrupting a normal flow pattern.

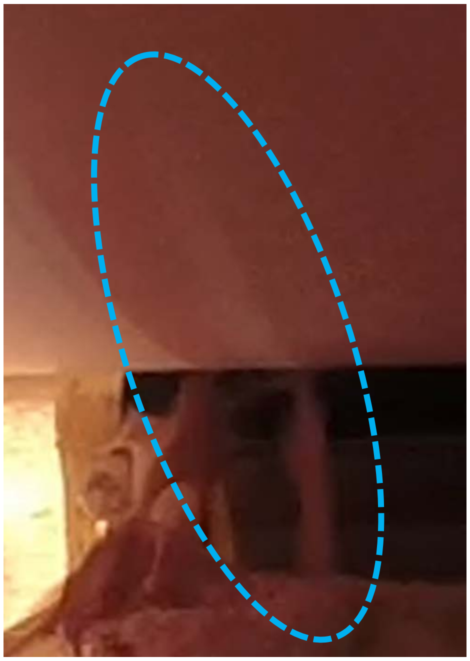

Figure 5. Image taken from a video of K15 at 73.7% solids content and a roll speed of 457.2 m/min displaying a spit from the blade and defect on the substrate surface. Paper is on top moving upward and blade is dark region at the bottom

Summary

The operational limits of blade coating of a paper web with suspensions with different aspect ratios is given. Dewatering of the suspension played a minor role in the results. The high aspect ratio pigment had maximum operational solids that was around 20% less than the moderate aspect ratio pigment. The operational limits do not correlate with steady shear viscosity but do relate to the difference of solids between the immobilization solids and the suspension solids. The limit seems to be related to the jamming of pigments together as they are sheared in the blade-web gap.

Acknowledgements

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Works Cited

Engström, G., & Rigdahl, M. (1989). Stalagmite formation during blade coating. The effects of process conditions. *Tappi journal*, *72*(8), 135-138.

Gane, P. A. C. (1997). Relaxation-induced dilatancy in separable visco-elastic suspensions: proposing a novel rheological phenomenon. In *1997 Tappi Advanced Coating Fundamentals Symposium*.

Gane, P. A., Hooper, J. J., & Grunwald, A. (1997). Coating pigment orientation: a comparative analysis of the application mechanisms and properties of blade and roll coatings. *Tappi journal*, *80*(2), 109-115.

Gane, P. A., McGenity, P. M., & Watters, P. (1992). Factors influencing the runnability of coating colors at high speed. *Tappi journal*, *75*(5), 61-73.

Weeks, L., "Operational limits of blade coaters associated with high aspect ratio pigments". PhD thesis, University of Maine, 2017.

Weeks, L., Bousfield D.W., & Lyons, A. (2016). The Influence of Pigment Concentration, Particle Size Distribution, and Aspect Ratio on Rheology. *PaperCon Conference Proceedings,* TAPPI Press, Atlanta, GA.

Weigl, J., & Grossmann, H. (1997). Factors impeding high-speed runnability of blade coaters. *Tappi journal*, *80*(11), 223-232.