THE MECHANICS OF WEB RELEASE FROM A ROLL DURING SIZE PRESS OPERATION

Rajan Iyer* and Douglas W. Bousfield **
(*)IMERYS, 618 Kaolin Rd. Sandersville, GA 31082

(**)Paper Surface Science Program, Department of Chemical and Biological Engineering
University of Maine, Orono, ME 04469

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In printing, size press, and metered size press coating operations, the paper web passes between two rolls and exits the nip causing a film to split between the web and the roll. The physics of the film split location is not well understood. If coating both sides of the web, the web release point can oscillate from top and bottom rolls generating non-uniform product. Experimental and modeling efforts here attempt to describe the physics of the situation.

A pilot scale metered size press coating unit was run at various speeds, coat weights, and coatings. The location of the web release from the roll was recorded with a camera. Figure 1 is a schematic of the pilot coater. The web tension is controlled to a well known level. From the digital images, the distance from the nip center to the web release point was obtained.

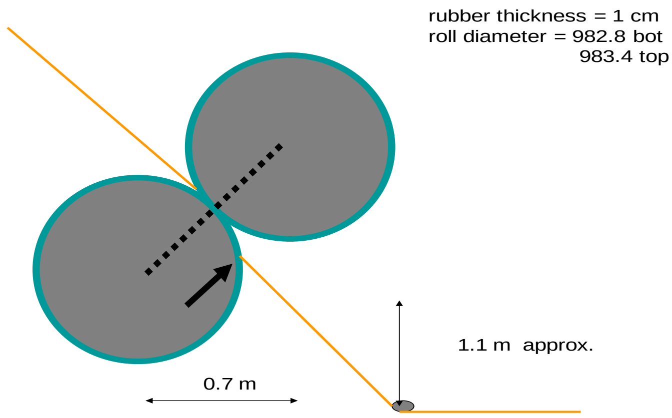

Figure 1. Schematic of pilot coater. Distance from nip center to release point is of interest.

The parameters that were considered are shown below:

- Ten coatings. High Shear Viscosity   40 – 55 cp.
- Speed   900 – 1350 m/min
- Coated both sides   15- 22 g/m^2
- Web tension 240 N/m
- Felt side down and take up point towards lower side.
- Measure take-off point.
- Rubber thickness = 10 mm

The conservation of mass and momentum, given in a lubrication type limit, is

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$$\frac{\partial P}{\partial x} = \frac{12\mu \ (h(x)(U_w + U_1)/2.0 - h_1 U_1)}{h(x)^3} \tag{1}$$

Where *P* is pressure, μ is viscosity, *h(x)* is the local distance between the web and the roll surface, U_w is the web velocity, U_1 is a roll surface velocity, and h_1 is the inlet fluid film thickness. For all cases studied here, the web and roll surface velocities are assumed to be the same.

The web is assumed to deform according to relationships for thin foils or sheets. In that literature for forming fabrics, it has been found that the stiffness and inertia to bending can be neglected, giving a simple expression for the curvature of the wire to the pressure difference over the wire, and the tension. The expression is

$$\frac{\partial^2 h_w}{\partial x^2} = \frac{\Delta P}{T} \tag{2}$$

Where h_w is the distance of the web to some reference plane, ΔP is the pressure difference over the web, and *T* is the web tension. The expression is analogous to the pressure difference generated by surface tension. The second derivative of the web position is a curvature of the web. This curvature must match the pressure difference. If the tension is high or the pressure is the same on either side of the web, the web does not deflect. If the web wraps a roll of radius *R*, the pressure in the fluid layer should be *T/R*.

For results presented later, the inlet location is adjusted to match the nip loading. The value of the minimum clearance, h_o is found. In most all cases, h_o is less than the inlet fluid layer thickness. This leads to the prediction of a decreasing pressure after x=0, because the terms in Eq. (1) generate a negative value. A pressure below atmospheric bends the web away from the roll surface. However, once the gap becomes greater than the inlet thickness, the pressure increases. This increase in pressure works to bend the web back towards the roll surface. This interplay of fluid and mechanical forces determines the location of the film split.

The exact boundary condition to use at the film split location is not clear. However, in the calculation, what happens without any additional terms, is that the web at some point is pulled away from the roll, the distance between the web and the roll *h(x)*, increases in Eq. (1), and the gradient in pressure goes to a small value. If this pressure is small, it will not deform the web. Therefore, the release point is when the gap simply becomes large enough to not cause pressure gradients in the fluid layer. This still leaves a “non-atmospheric” pressure in the fluid layer, but it is expected that the actual split of the film will involve surface tension forces that will work to adjust the pressures. In addition, other phenomena, such as cavitation, may influence the pressure field. Therefore, instead of trying to model details of the film split event with surface tension forces, we assume here that when the fluid layer is larger than ten times the inlet fluid layer thickness, that the film has split.

After the film split, the web trajectory is adjusted to move towards a take up point. If the take up point is high or low, the web trajectory is influenced by the web tension and how far away from the preferred path. Equation (2) is modified to account for the force along the web due to deformation away from the take-up location as

$$\frac{\partial^2 h_w}{\partial x^2} = \frac{\Delta P}{T} - \frac{FU\Delta S}{T\Delta X} \tag{3}$$

Where ΔS is the difference of the current slope of the web and the slope of the line that goes to the take-up location. F is some factor, that would have units of Ns/m^2, that controls how rapidly the web responds to the long distance tension of the system, and ΔX is the distance of current location to the x position of the take-up point. The factor of F= 1MNs/m^2 gives results that seem to be reasonable. This second term is similar to bending a web under tension from the tension plane, but also contains "inertia" of the system. A more careful mechanical analysis of this situation may improve Eq. (3), but for now, this form seems to give reasonable results.

Equations (1) and (3) are integrated by standard finite difference method for a second order differential equations. The increment in the x direction should be less than 0.1 µm. The curvature in Eq. (3) changes the slope of the web. The slope is used to change the relative elevation of the web. The distance between the web and the roll surface determines the gap h(x) used in Eq. (1). For the inlet to the nip, only Eq. (1) is integrated to obtain the pressure distribution.

Figure 2 shows the predictions of the model for conditions as noted in the figure. The web deflects downward due to the hydrodynamic forces between the web and the roll surface. The pressure field between the web and the roll surface fluctuates positive and negative as the gap increases and decreases around the inlet fluid thickness. At 60 mm from the nip exit, the gap increases to a level that is now too large to influence the web deflection: the pressure gradients become too small to change the pressure. This point is called the release point.

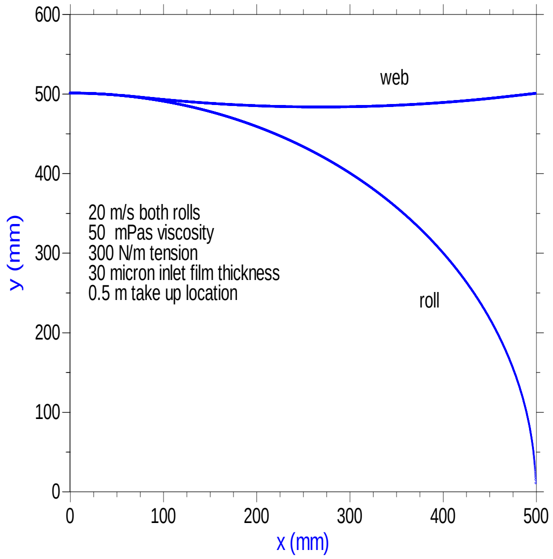

Figure 2. The web trajectory and the roll surface position for 20 m/s web speed, 50 mPa.s viscosity, 300 N/m tension, and 30 mm inlet film thickness. The take-up point is 0.5 m in the vertical direction from the bottom roll center. The release point is 60 mm from the nip center.

The influence of web tension is shown in Figure 3. As expected, low tensions allow the web to follow along with the roll surface a significant distance before it is pulled from the surface. At high tension, the web comes straight out of the nip and deforms only a small amount.

Figure 4 shows the measured and predicted take-off point. The various coatings had similar values. Only two speeds could be collected due to some steady state issues, but the results are encouraging. While the model under predicts that release point, the values are close and the trend in the model is correct.

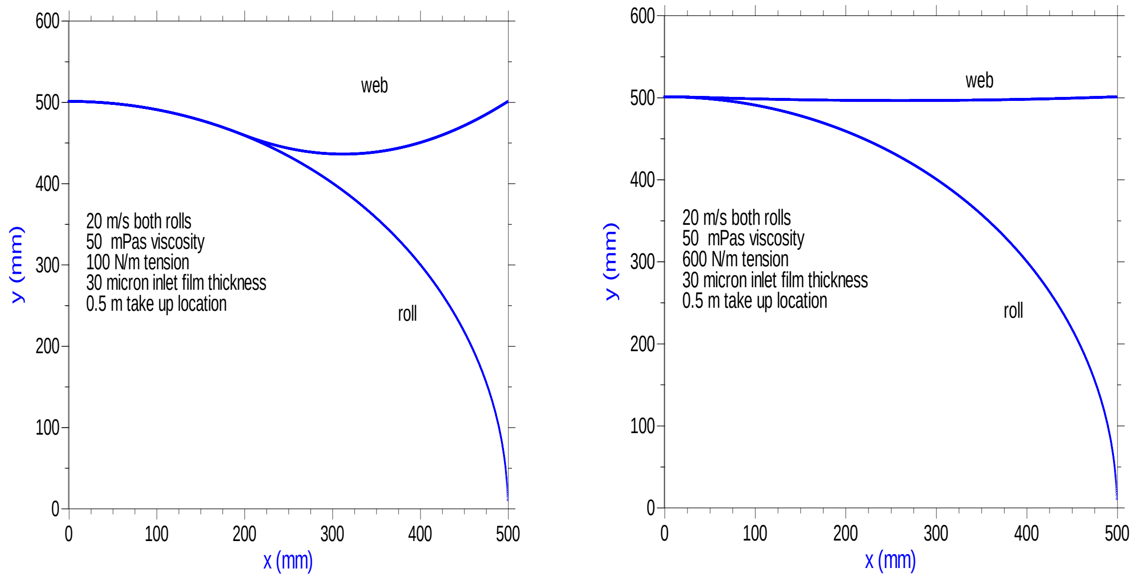

Figure 3. Low and high tension cases, left and right, respectively, for conditions indicated in the figure.

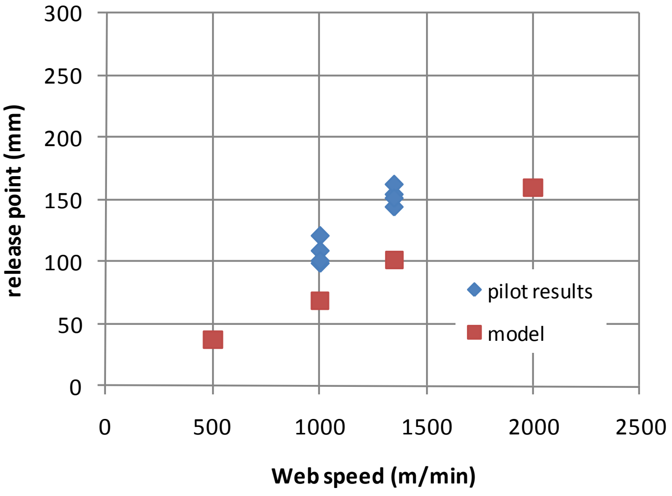

Figure 4. Comparison between the model predictions and pilot scale results.

Comparison with the data of Gron et al (1998) is also reasonable, but some trends in the model are not always as expected.

Grön, J., Nikula, E., Sunde, H., "Influence of Coating Composition on Web Release in High Speed Film-Transfer Coating", TAPPI J., 81(1) 216-225 (1998).