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Effect of viscoelasticity on dynamics and stability in roll coatings

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The final goal of most coating flows is to produce uniform coating liquid layers of specified thickness at high speeds. The study on the dynamics and optimal coating windows in coating processes is quite important industrially as well as academically, because it is closely related to productivity and high quality control of coating products, especially, in films, flat panel displays, batteries, and steel products. Recently, rheological aspects of viscoelastic coating liquids on the coating dynamics have attracted researchers' interest, since non-Newtonian behavior in coating flows can change the performance of a coater (Dontula, 1999).

Among many coating processes (e.g., roll; slide; slot; curtain coatings, etc.), in this study, forward and reverse roll coating processes have been experimentally investigated, which are distinguished by the use of one or more gaps between rotating rolls to meter and apply a liquid to web or substrate (Benkreira, 2002; Coyle et al., 1990; Tiu et al., 1999). To examine the flow dynamics of Newtonian (Glycerine/water, etc.) and viscoelastic liquids (a mixture of polyacrylamide and Newtonian liquid, etc.) near coating beads in both processes, coating thickness and positions of dynamic contact line or meniscus have been measured under various operating conditions, using the flow visualization apparatus (Fig. 1). It has been found that the viscoelasticity in coating liquids makes the film thickness somewhat thinner and positions of meniscus or dynamic contact line lower, resulting from the elastic stress or extensional stress in downstream coating bead (Figs. 2-3).

Also, coating windows of Newtonian and viscoelastic liquids in forward and reverse roll coating processes have been established, respectively. In the forward roll coating, the viscoelasticity aggravates the ribbing instability, meaning that ribbing occurs under the lower roll-speed conditions in viscoelatic case. The destabilizing effect of the viscoelasticity is caused by the high elastic stress near the downstream region, prominently making the pressure gradient in the downstream positive. There are two instability modes in the reverse roll coating: ribbing in low speed ratio of metering roll and applicator roll and cascade in high speed ratio between both rolls (In the middle speed ratio, stable region exists). It has been observed that in this system the viscoelasticity produces the stable regime at higher speed ratio than Newtonian case. This result may be also closely related to the extensional flow near the downstream metering flow region.

To elucidate the effect of viscoelasticity on the roll coating dynamics, extensional properties of both Newtonian and viscoelastic coating liquids have been measured and compared using extensional indexers. We have concluded that extensional properties in coating liquids play a key role in determining the optimal coating windows and the coating performance. We will report more detailed results on this issue in ECS2007.

References

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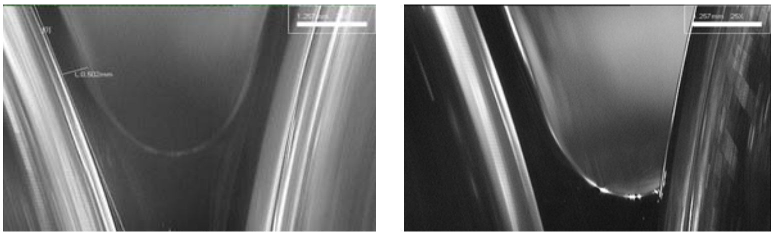

(a) (b)

Fig. 1. Downstream menisci (a) in forward roll and (b) in reverse roll coatings.

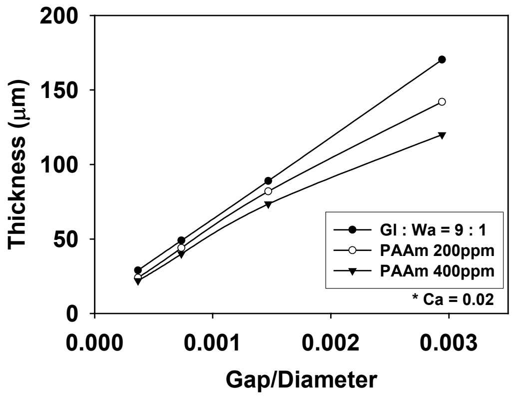

Fig. 2. Effect of gap size between two rolls on the coating thickness in forward roll coating.

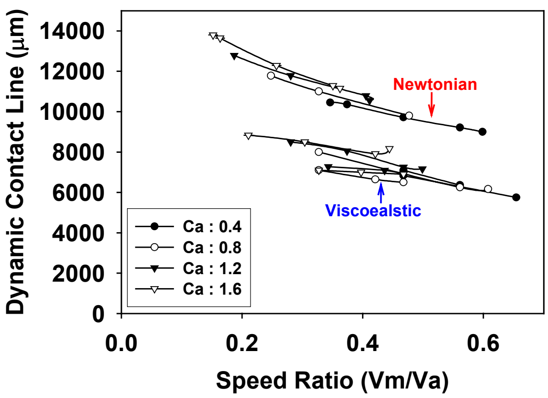

Fig. 3. Effect of speed ratio on the position of contact line in reverse roll coating.