Visualization study of flow stability in two layer reverse roll transfer

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Introduction

Reverse roll coating in which a thin single layer of liquid is applied onto a substrate has been used in industry for decades and has been extensively analyzed in the literature. Modern coatings, however, are often composed of more than one layer to improve product performance and to reduce manufacturing cost. Pre-metered methods such as slot, slide and curtain coating are typically are used to produce such multilayer coatings. If the caliper of the substrate to be coated is not constant, the coating gap and consequently the final film thickness deposited on the web will also be non-uniform. These drawbacks of precision multilayer coating can be avoided in cases at which the final product uniformity requirement are not a limiting factor by coating two liquid layer onto an application roll using two layer slot coating and transferring it to the substrate in a reverse roll transfer process. In order to implement this approach in an industrial line, it is important to determine the set of conditions and liquid properties at which the transfer film remains uniform. To our knowledge, a systematic study of these conditions has not been reported in the literature. In this study we focused on the use of reverse roll technique with slot die liquid delivery system to produce a uniform thin two-layer coating. The liquid film surface as it is transferred from a rigid steel roll to a deformable urethane covered roll was visualized in order to find out how the uniformity of two layer coating is affected by the speed ratio between two rolls, wet thickness and liquid viscosities. The effect of these parameters on the ribbing frequency and amplitude was also investigated.

Experimental set-up

The experimental set-up is shown in Fig.1. The roll coating apparatus used in these experiments and located in the Coating Process and Visualization Laboratory at the University of Minnesota has 4 inch diameter rolls installed one above the other. A high speed camera and a high-resolution digital camera were used for visualizations of the flow. Glycerine-water solutions were used as the coating liquids. The viscosity of the solution was adjusted by dilution with water. To make the flow visible, a fluorescent dye (Fluorescein disodium salt, 2-hydrate (green, which was dissolved in the coating the coating solution) injected inside the bottom layer distribution chamber of the die.

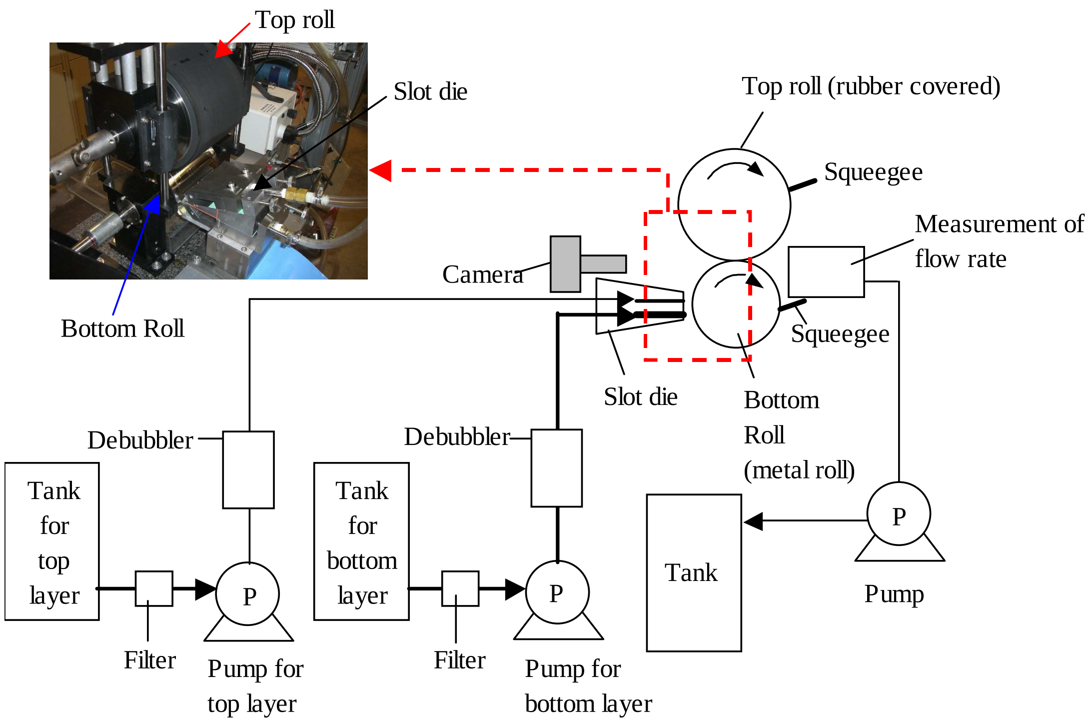

Fig. 1. Sketch of coating apparatus.

Results

The onset of ribbing can be determined by observing the streaklines formed by the injected dye at different top to bottom roll speed ratio, as shown in Fig. 2. The viscosities of the top and bottom layers were 20cP and 5cP, respectively. The ratios of the wet thickness and gap of the two rolls were $h_{top}/H=0.4$ and $h_{bottom}/H>0.4$, respectively. The speed of the bottom roll was kept constant at 30mpm. The flow rate from the dye injection syringe was adjusted so that the fluorescent dye band was about 0.6mm wide on the bottom roll. The lower part of the picture shows the bottom roll, the central part shows the transfer meniscus region and the upper part shows the top roll. The coating liquid moves from the bottom roll to the coating bead and is then transferred to the top roll. When the speed ratio between two rolls was below 3.46, the streakline was straight without variation in width, indicating a two-dimensional flow. At speed ratios above 3.69, the dye streakline width on the top roll increased, indicating a three-dimensional flow. The movement of the coating liquid from the roll at the bottom to the top roll was almost uniform in the stage before ribbing, and with the generation of ribbing, the results confirmed diffusion in the width direction along the ruggedness of the ribbing. The onset of the three-dimensional pattern can be determined by tracking the streakline width ratio, defined as the width of the dye band on the top roll to that on the bottom roll, as a function of the speed ratio, as shown in Fig. 2 and 3.

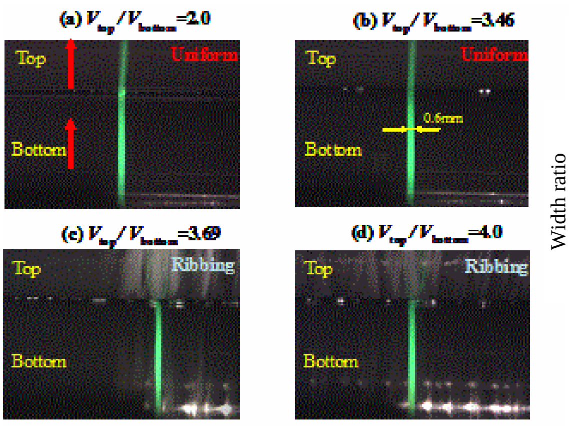

Fig. 2. Visualization of tracer movement.

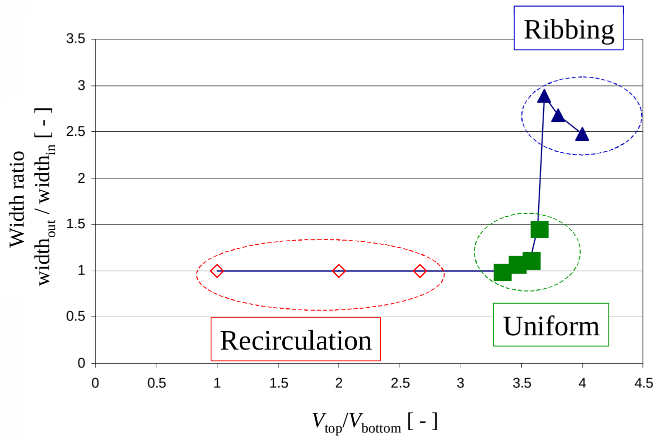

Fig. 3. Relationship between speed ratio and width ratio of tracer

At speed ratios below 3.6, the width ratio is close to 1.0, indicating a two-dimensional flow. The speed ratio at which ribbing occurs is clearly marked by a sudden increase in the width ratio.

The width of the dye was widest at the onset of ribbing, and it follows that it gradually decreased as the speed ratio increased. It is thought that the ribbing wavelength had a low frequency at the onset of ribbing, and a wave of wide wavelength was generated in the width direction and was transferred to a high frequency with increasing roll speed.

Conclusion

The liquid film surface as it is transferred from a rigid steel roll to a deformable urethane-covered roll was investigated in order to determine how the uniformity of two-layer coating is affected by the speed ratio between two rolls, the wet thicknesses of the layers and the viscosities of the liquids. The conclusions are summarized as follows.

(1) Liquid transfer is uniform before ribbing generation, and after ribbing generation, the liquid spreads to the width direction along the jaggedness of the ribbing.

(2) The results show that, in two-layer coating, as in single-layer reverse transfer coating, there is a critical web speed above which ribbing occurs.

References

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