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Flow Control and Die Design in Patch Slot Coating

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Abstract

Flow dynamics of Newtonian and Non-Newtonian fluids in patch slot coating process, which is used in manufacturing IT products, has been investigated. Actually, the flow control in this system is more difficult than in continuous case because of its transient nature. The internal die and die lip designs for uniform coating products have been suggested by controlling flow patterns of coating liquids issuing from slot die. Numerical simulations have been performed using Fluent and Flow-3D packages. It has been found that both Newtonian and shear thinning fluids exhibit their characteristic head and tail coating shapes in single coating pattern, leading to their own optimal die structures.

Introduction

Slot coating process, in continuous and patch (or intermittent) modes, has been applied for the many precise coating products, e.g., flat panel displays and Li-ion batteries. However, manufacturing uniform coating products is not a trivial task at high-speed operations because various flow instabilities or defects such as leaking, bubbles, ribbing, and rivulets are frequently observed in this process. It is no wonder, therefore, that many efforts to understand the various aspects of dynamics and coating windows of this process have been made both in academia and industry.

In this study, flow dynamics of both Newtonian and Non-Newtonian (shear thinning) liquids in patch or intermittent slot coating process, which is employed in manufacturing IT products such as the secondary batteries, has been investigated for the purpose of optimal process designs. As a matter of fact, the flow control in this system is more difficult than in continuous case because of its transient or time-dependent nature. The internal die and die lip designs for uniform coating products have been obtained by controlling flow patterns of coating liquids issuing from slot die. Numerical simulations have been performed using Fluent and Flow-3D packages. Flow behavior and pressure distribution inside the slot die have been compared with various die internal shapes and geometries. In the coating bead region, efforts to reduce irregular coating defects in head and tail parts of one coating pattern has been tried by changing die lip shapes.

Results and Discussion

As the first case, flow behaviors inside the slot die have been theoretically examined by three-dimensional (3-D) Fluent simulation. Effect of internal die design on the cross-web uniformity of coating liquids, both Newtonian and shear thinning liquids, at the slot die exit has been analyzed. For the shear thinning liquids which are strongly dependent on the die geometries, an optimized internal die has been sought assembling merits of each die geometry such as chamber size, coat hanger, converging shape, slot length, etc, giving the uniform velocity distribution of coating liquids at the die exit (Fig. 1). Also, transient velocity and pressure profiles inside the die have been compared for the patch slot coating applications.

As the second case, flow dynamics of both Newtonian and non-Newtonian liquids in patch slot coating mode has been focused for its optimal process design. Coating liquids are intermittently coated on the web under the start-up and cut-off conditions. Numerical simulations of the coating bead flow have been performed using Flow-3D. It has been found that the initial bump of coating liquids under the start-up condition has been drastically reduced with increasing capillary number, as shown in Fig. 2a. Also, the shorter downstream die lip effectively lessens the coating defects in head and tail parts of one coating pattern (Fig. 2b).

It has been concluded that optimal die internal design has been developed guaranteeing uniform velocity distribution of both Newtonian and shear thinning liquids at the die exit. And also optimal die lip design has been established, providing the longer uniform coating layer thickness in coating patterns.

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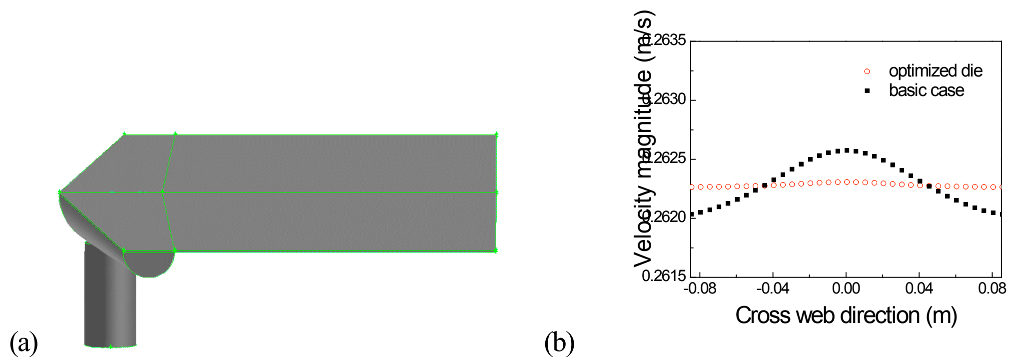

Fig. 1. (a) Example of optimized die design for the given shear thinning liquid and (b) velocity profiles along with die width direction at die exit using basic semi-circular and optimized dies.

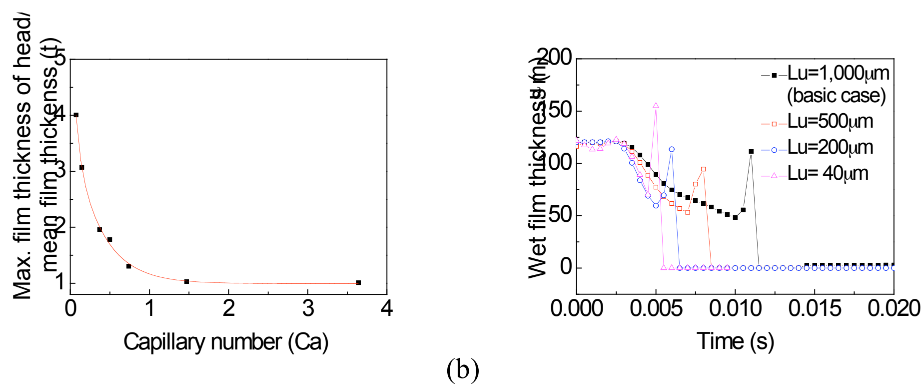

Fig. 2. (a) Maximum wet film thickness at start-up condition plotted against the capillary number and (b) transient wet film thickness profiles depending on the downstream die lip length.