Continuous 와 pattern slot 코팅 공정에서의 유동특성과 다이 설계

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Dynamics and die design in continuous and patch slot coating processes

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Abstract

Slot coating process, in continuous and patch modes, has been applied for the many precise coating products, e.g., flat panel displays and second 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, as the first topic, flow dynamics within the coating bead in slot coating process has been investigated using the one-dimensional viscocapillary model by lubrication approximation and two-dimensional model by Flow-3D software. Especially, operability windows in both 1D and 2D cases with various slot die lip designs have been successfully portrayed. Also, effects of process conditions like viscosity and coating gap size on slot coating window have been analyzed. Also, some experiments to find minimum coating thickness and coating windows have been conducted using slot die coater implemented with flow visualization device, corroborating the numerical results.

As the second topic, flow dynamics of both Newtonian and Non-Newtonian fluids in patch or pattern slot coating process, which is employed in manufacturing IT products such as 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 patterned uniform coating products have been obtained by controlling flow behaviors 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 has 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 patterned coating unit have been tried by changing die lip shapes. It has been concluded that optimal die internal design has been developed, guaranteeing uniform velocity distribution of both Newtonian and shear thinning fluids at the die exit. And also optimal die lip design has been established,

providing the longer uniform coating layer thickness within one coating unit.

Theory and experiment

Simplified 1D viscocapillary model to predict the slot coating flow has been developed by assuming the rectilinear flow in coating beads (Ruschak, 1976; Higgins and Scriven, 1980; Kim et al., 2005). Flow behavior in the upstream and downstream regions in this case can be described as a combination of the Couette flow caused by the moving web and the Poiseuille flow by bead pressure drop with the continuity condition. The location of upstream meniscus and pressure distribution within coating bead have been estimated from this model. These results have been compared with those by Flow-3D software and experiments. For the study of optimal die designs, three-dimensional flow behavior inside slot die has been examined by Fluent and two-dimensional flow behavior in coating bead has been investigated by Flow-3D, respectively.

Results and discussion

In this paper, the effect of internal and external die geometries for non-Newtonian fluid was studied, and optimal die designs were suggested. Fig. 1 and Fig. 4 show the various internal die and external lip shapes, respectively. Internal die design is important because the liquid passage in internal die has the biggest impact on the cross-web uniformity of coated liquid. Regarding pattern slot coating, in the start-up condition, coating liquid issuing from the slot die first forms its protruding head with larger coating thickness than its steady value. And when the feeding is cut off, the tail part of coating becomes thin and is finally broken. Actually, non-uniformity of the head and tail parts of coating should be reduced in pattern coating, especially, in the manufacture of battery cells, because film thicknesses at the start-up and end points are thicker and thinner than steady value in the middle part, respectively. So it is required to find optimal die lip design to reduce defect length at the start-up and end conditions.

Internal die mainly consists of a chamber and a slot. Larger chamber size improves cross-web uniformity at the die exit, while it adds up flow residence time and leads to dead zone area where flow nearly stagnates. In addition, although longer slot length enhances cross-web uniformity, it increases flow resistance against slot die. By adjusting chamber shape, cross-web uniformity can be improved without an augmentation of residence time, dead zone, and flow resistance. Fig. 1 shows coat-hanger die with features decreasing slot length along with cross-web distance and converging die reducing chamber size along with cross-web distance (Kistler, 1997). Combination of coat-hanger and converging die design provides uniform cross web velocity profile at the die exit, as shown in Fig. 2. Optimal internal die design is shown in Fig. 3.

Length scale of head and tail parts in pattern coating depends on die lip design. To examine the effect of slot die geometry on the flow patterns, four die lip designs have been considered, as displayed in Fig. 4. By reducing downstream die lip length, length of uniform coating layer increases under the end condition, while it dose not change under the start-up condition, as shown in Fig. 5. The reason is why under the end condition downstream die lip shape directly decides the amount of coating liquid which remains between die lips and substrate and then forms unsteady film thickness. However it is possible that with inclination of downstream die lip (knife die shape, Fig. 4c) coating liquid climbs downstream die lip and then length of tail defect increases. Moreover, converging die shape (Fig. 4d) can diminish not only head defect length but also tail defect length. It has been found that minimum defect length is obtained by applying converging die lip design. Also, it has been concluded that we can establish the optimal process conditions by developing die design for uniform coating products with high quality and productivity in pattern slot coating.

References

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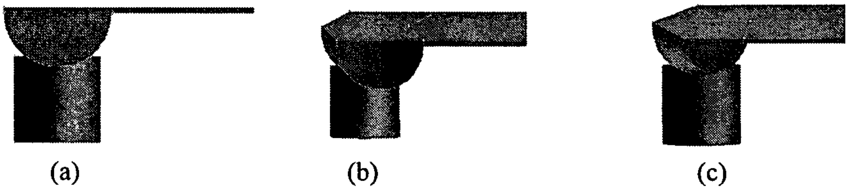

(a) (b) (c)

Fig. 1. Internal die shapes: (a) standard (hemi circle), (b) coat-hanger, and (c) converging.

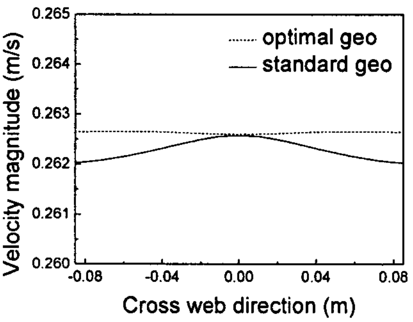


Fig. 2. Cross-web velocity profile at die exit.

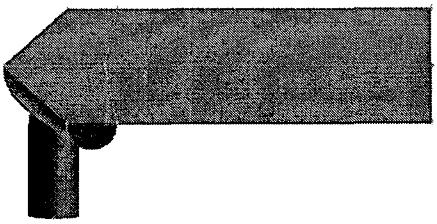


Fig. 3. Optimal internal die design.

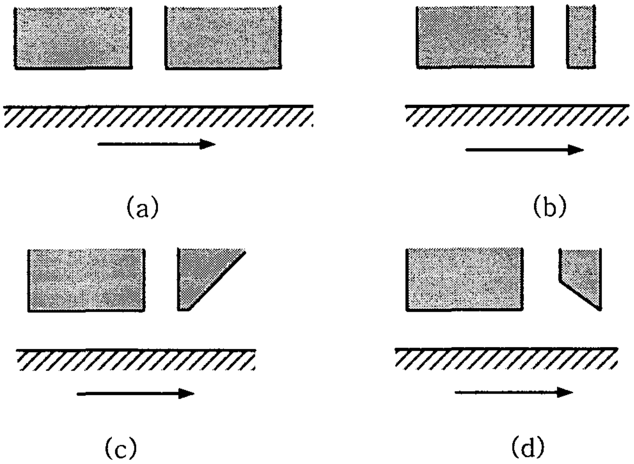
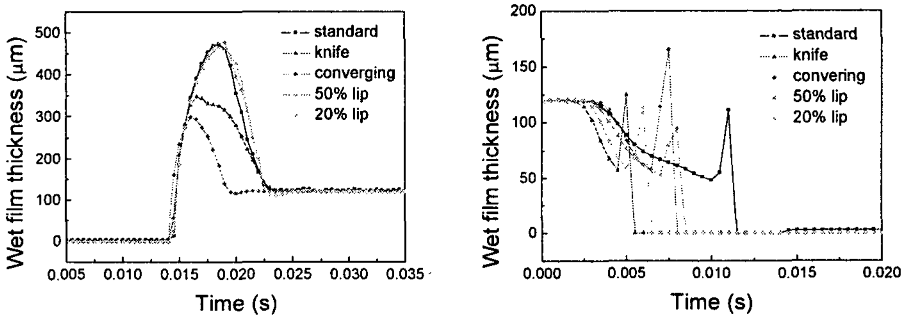


Fig. 4. Die lip shapes: (a) standard, (b) shorter upstream lip, (c) knife, and (d) converging.



(a) (b)

Fig. 5. Transient film thickness profiles in non-Newtonian cases under (a) the feed start up and (b) end conditions.