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Interface Analysis of Three-layer Co-extrusion Blown Film

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Abstract. The three-layer co-extrusion blown film could combine a variety of different characteristics in the extrusion process and significantly decreased cost, therefore this technology is being applied more and more broadly. The flow channel geometry of three-layer co-extrusion blown film die was built and then meshed by ICEM CFD with all-hexahedral elements whose flow field numerical simulation was solved by POLYFLOW to analysis the interface shape and position for LDPE/HDPE/LDPE three-layer co-extrusion blown film. It shows that the interface fluctuates when each layer met in the co-extrusion channel. The differential pressure of two adjacent layers bring about interfacial deformation, interface position changes due to the flow channel rearrangement when each layer met the co-extrusion channel.

Keywords: multilayer co-extrusion blown film; numerical simulation; interface.
PACS: 82.20 Wt

INTRODUCTION

With the increasing demand for the performance of packaging materials, the single-layer packaging material has been unable to meet the special requirements of the packaging film or sheet products and the multi-layer composite packaging film can meet these requirements due to the composite properties of each layer [1]. With the developing of co-extrusion technology, multi-layer co-extruded films have attracted widespread concern.

During co-extrusion, the interface between the layers will be deformed. In addition to the evaluation criteria for single-layer extrusion products, the quality index of the co-extruded product also contains the thickness distribution of each layer and the shape of the interface. C.D.Han and his colleagues have made outstanding contributions in the co-extrusion one-dimensional calculations [2], their research revealed some basic laws of co-extrusion flow: velocity and shear stress continuing at the interface; existing viscous encapsulation; when the lower viscosity components flow outside the higher viscosity components, the pressure is lower than when any of the components flow independently [3-7]. Perdikoulias[8] experimented with four different molecular weight distribution low-density polyethylene in a two-layer co-extruded ring die. Pointed out that the material with wide molecular weight distribution was more intend to the instability of the interface. Anderson [9] has studied the co-extrusion flow of polystyrene in the rectangular flow channels and found that the elastic rearrangement caused by the second normal stress difference may form very complex interface shapes. Co-extrusion technology could combine a variety of different characteristics in the extrusion process and decrease cost. The co-extrusion die is the core components in the processing of composite packaging materials. In this paper, a structure of three-layer co-extrusion blown film with planar superimposed spiral die is designed. The layer attribution channels of each layer of melt are similar in structure and each layer of melt merges in the co-extrusion flow channel in a composite sequence to complete the compounding.

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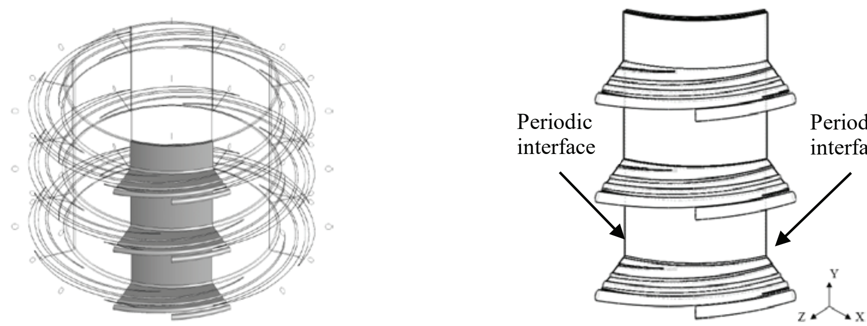
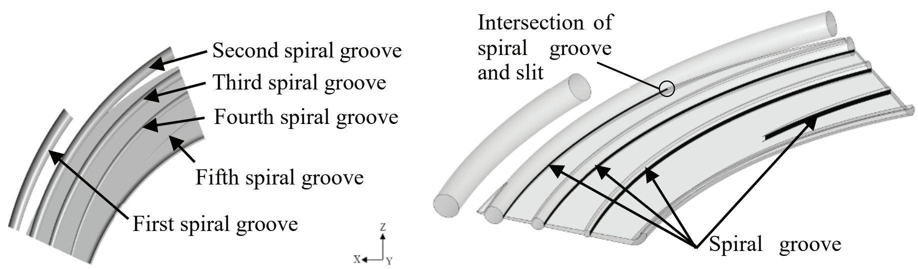
STRUCTURE OF THREE-LAYER CO-EXTRUSION BLOWN FILM

As shown in FIGURE 1 and FIGURE 2, for the three-layer co-extruded blown film plane superimposed screw die, the spiral distribution system is the main structure. This molding die produces ABA type three-layer co-extrusion blown film using two or three extruder, and the material combination structure is LDPE/HDPE/LDPE. The structure is characterized by periodic symmetry clearly. In order to reduce the calculation scale and improve the calculation accuracy, the simulation of 1/8 flow channel with periodic boundary was carried out. The plane of the periodic boundary entry is the plane formed after the XY plane around the Y-axis in the -22.5° and the plane of the periodic exit is the surface formed after the XY plane around the Y-axis in the -67.5°.



(a) Axonometric drawing (b) Periodic boundary

FIGURE 1. Flow channel geometry



(a) Number of spiral grooves (b) Intersection of spiral groove and slit and Spiral groove exit

FIGURE 2. Names appointed for spiral distribution system

MODELING AND BOUNDARY CONDITIONS

Mathematic model

During the process of co-extrusion, the flow channel structure and the rheological behavior of the polymer are complex. In order to facilitate calculation and accord with the actual processing conditions, the simplification and hypothesis of the numerical simulation are that the polymer melt is an incompressible fluid and the melt is isothermal and stable laminar flow. The melt is incompatible and no-slip conditions. The interfacial tension, volume force, and inertia force are neglected.

Continuity equation (Eq.1):

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho V = 0 \tag{1}$$

where $\boldsymbol{V}$ is velocity, m/s, ρ is melt density, kg/m^3.

Momentum equation (Eq.2):

$$\rho \frac{dV}{dt} = \nabla \cdot \tau - \nabla P + \rho g \tag{2}$$

where P is hydrostatic pressure, Pa, τ is stress tensor, Pa, g is gravity acceleration, m/s^2.

Constitutive equation:

The constitutive equation of the generalized Newtonian fluid (Eq.3):

$$\tau = \eta(\dot{\gamma})\dot{\gamma} \tag{3}$$

where $\boldsymbol{\eta}(\dot{\boldsymbol{\gamma}})$ is non-Newtonian viscosity (apparent viscosity), Pa·s, $\dot{\boldsymbol{\gamma}}$ is shear rate tensor, 1/s.

FEM model

The flow channel geometry model was established in SOLIDWORKS and then meshed by ICEM CFD with all-hexahedral elements. Y positive direction is the extrusion direction, the XY plane is the reference, and the Y is the rotation axis.

Physical parameters

The material used for simulation analysis is Low-Density Polyethylene (LDPE) and High-Density Polyethylene (HDPE). The rheological parameters of LDPE and rheological parameters of HDPE were shown in Table.1.

TABLE (1). Physical parameters of material

Material	Non-Newtonian index	Relaxation time /s	Zero-shear viscosity /Pa·s
LDPE	0.32	0.036	1807
HDPE	0.5	0.08	1520

Boundary conditions

(1) Entrance boundary: Considering the periodic symmetry of the model, the volume flow rate is calculated according to the 1/8 model. The volume flow rate of the first layer LDPE inlet boundary is 2.64×10^{-7}m^3/s, and the ratio of the first, second, third layer volume flow rate is Q1:Q2:Q3=1.5:1.5:1.

(2) Flow channel wall boundary: The simulation analysis uses the no-slip conditions and adopts the Navier slip law for approximation to reduce the computational difficulty of convergence (Eq.4).

$$f(V) = -k(V_s - V_{wall})^e \tag{4}$$

where $f(V)$ is shear stress, Pa, V_s is tangential velocity of the melt on the wall, m/s, V_{wall} is wall tangential velocity, V_{wall} = 0m/s, k is the slip coefficient, k = 108Pa·s/m, e is nonlinearity, e =1.

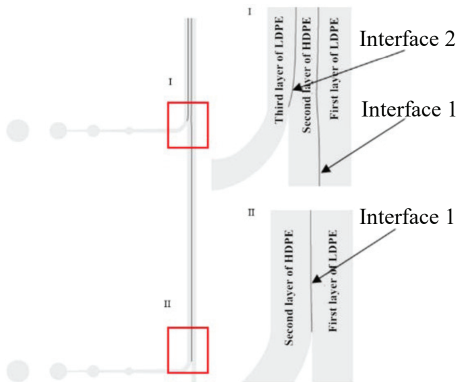
(3) Periodic boundary: Positive direction of the Y-axis is the center of the model, altering by the -45° periodically. Inlet boundary and exit boundary are set to form periodic boundaries.

(4) Interface boundary: The velocity at the interface is continuous and the melt cannot pass through the interface, V_n=0, the shear stress and normal stress on both sides of the interface are continuous.

(5) Outlet boundary: Neglecting the effect of drafting and bulging of the membrane bubble f_n=0, f_s=0.

INTERFACE ANALYSIS

The overall interface appearance and the local enlarged drawing of on the interface of the second, third layer attribution of the cross section are shown in FIGURE 3.



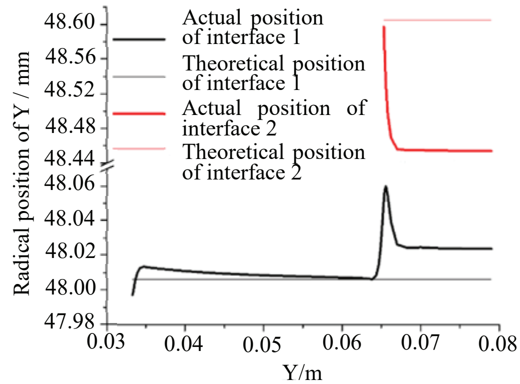
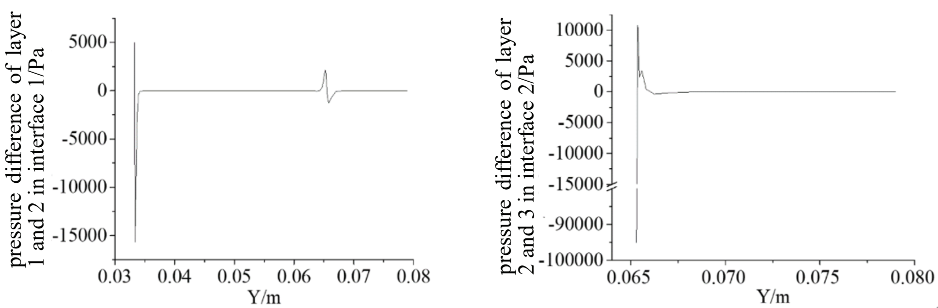


FIGURE 3. Interface pattern on section I **FIGURE 4.** Interface position on section I

As shown in FIGURE 3 and FIGURE 4, because of secondary flow, the fluctuation at the interface of the melt into the co-extrusion channel at each layer occurred.

In order to analyze the cause of secondary flow, the pressure difference of the melt in the adjacent layer on the interface 1 and the interface 2 (shown in FIGURE 5) was analyzed.



(a) Interface 1 (b) Interface 2

FIGURE 5. Pressure difference

Compared with FIGURE 4 and FIGURE 5, the trend of pressure difference is agree with the trend of interface position. For example, in the attribution of layer 1 and 2, if the pressure difference is positive, the melt pressure of the first layer is higher and the interface 1 shifted to the layer 2. Conversely, the interface 1 shifted to the layer 1. Pressure difference is zero in co-extrusion channel when the interface is stable. The pressure difference between the adjacent layers on the interface that causes the secondary flow perpendicular to the extrusion direction, which result in the deformation of the interface.

FIGURE 6 shows the interface shape and the grid map after deformation. The location for interface 1 and 2 shows no alteration. In order to quantify that alteration, FIGURE7 was carried out.

As FIGURE 7 shows, the radial position of the interface 1 and the interface 2 are sine-like curves. The thickness of the first and third layer are sort of sine-like curves because of the existence of the exit wall. The thickness of the second layer is stable, but the thickness of the second layer is smaller than the theoretical value. Because of melt of the first and third layers flow near the wall and effected by the adhesion of the wall, the velocity near the wall is lower, so the larger flow section is needed to maintain the extrusion flow, the thickness of the second layer decreases.

FIGURE 6. Deformed mesh on the outlet surface

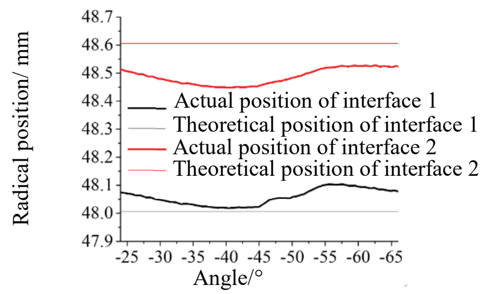


FIGURE 7. Interface position on the outlet surface

CONCLUSION

The pressure difference between two adjacent melts on the interface leads to the secondary flow in the attribution of each layer, which result in the pressure difference alteration. The location of interface 1 and 2 changes with such alteration.

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