Research on grid replacement technology and two-dimensional isothermal simulation on melt flow of blown film

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Abstract

Established a melt flow model of two-dimensional isothermal simulation for spiral mandrel blow-film die, analysed die swell-effect at the die exit of blown film extrusion process by grid replacement technology, obtained the pressure distribution in the internal flow of blow-film die, and analysed the shape change of free surface at die extrusion section with different viscosity materials. The results showed that the resistance force of the melt flow under internal flow of blow-film die mainly from the spiral direction, with depth of spiral groove gradually shoaled, the direction of resistance force changed from spiral direction to axial direction. When high viscoelastic material entered blow-film die being extruded, the shape of free surface at die extrusion section would change significantly, meanwhile, the gradient of radial velocity of melt flow in the internal die became gradually reduced.

Keywords: spiral mandrel blow-film die, grid replacement, die swell-effect, free surface

1 Introduction

The technology of extrusion blown film from thermoplastic plastic began in the thirties. The first device of polyethylene tubular film was produced in the United States about in 1939. Today, this production method is widely used by people. This was inseparable with multifaceted applications of polyethylene. More than 90% of the low density polyethylene films between a few centimetres to several meters in width, 0.02 to 0.3 millimetres in thickness are produced by the blow mould. Because of the economical of this method, it can not only make the products have great change, but also obtained some finishing effect through the same process. This is particularly important for the use of thin films.

With the continuous development and industry technology upgrade as well as people continuously improve the diverse needs of packaging products, the late nineteen eighties, multi-layer co-extruded high barrier film was developed successful. This material has a permeability resistance, oil resistance, can retort resistance, heat sealing, etc., can be used in various types of food and cosmetics packaging. It greatly extended the product's shelf life. Thus, the plastic film for packaging had a rapid development trend towards the functional, lightweight and greenery [1-4].

However, due to the polymer molding process exhibit complex viscoelastic behaviours, the research of the melt flow in the die of the internal flow is relatively slow, using the traditional method of mathematical analysis and experimental methods have greater limitations. With the maturing of CAE technology, more and more scholars have conducted to basic research; the problems of its reliability and calculation effecting have been resolved.

In 1982 PLYFLOW was developed at the University of Louvain, Belgium. In 1997 was acquired by the world famous fluid analysis software company FLUENT. It is suitable for plastics, resins and other polymer materials, extrusion molding, blow molding, drawing, laminar mixing, the coating process of the flow and heat transfer and chemical reaction problems. It may also be used to simulate the polymer flow problems, such as a polymer melt, oil, ink and suspended solids flow simulation [5-7].

In this paper, the finite element method and polyflow software was applied to the planar structure of spiral mandrel die by two-dimensional numerical simulation, explored using grid replacement technical to analyse the internal flow of the melt in the die and the effect of die swell-effect to the morphology of the die extrusion section.

2 Calculation model

2.1 GEOMETRY

Analysis model adopt the spiral mandrel die as a basis which has been widely used in co-extrusion composite technology. As the complex shape of the internal structure, modelling and design would be more difficult, using the POLYFLOW software to do two-dimensional planar analysis for die profile. As shown in Figure 1.

Spiral mandrel die using central feeding method, can ensure the melt suffered shear force equal in the cross-section of each point, die gap uniformity, metl film speed stability.

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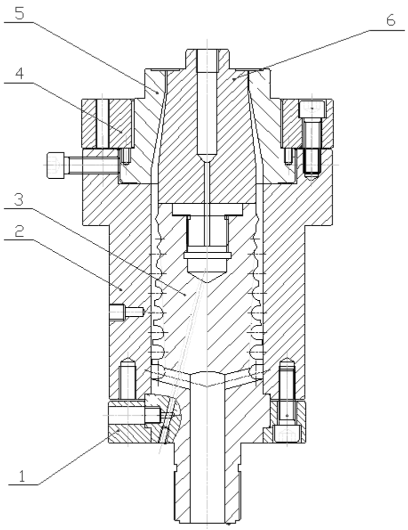

FIGURE 1 The internal flow channel of die head: 1. lower gland; 2. outer mold body; 3. spiral body; 4. upper gland; 5. adjust ring; 6. die

In the blown film process, the melt flow through spirochetes channel then being squeezed forcing through a die, so when to do the simulate, the outer mold body, the spiral body, the flow channel section and the die extrusion part (POLYFLOW set as the free surface) should deal with as two separate parts. Therefore, the thickness of extrusion section for free surface is taken of 2mm. The outer die body, upper and lower gland and adjustment ring can be neglected in simulation due to do not participate in the melt flow process.

2.2 MATHEMATICAL MODEL

In order to simplify the calculation, to do the assumptions of internal flow of melt in the die [8-10].
Assuming the melt in the die internal flow was isothermal flow, steady-state process and melt was incompressible, the continuity equation is:

$$\nabla v = 0 . \tag{1}$$

Ignore the melt gravity and inertial force.
The momentum equation is:

$$\nabla \tau - \nabla P = 0 , \tag{2}$$

where v is velocity vector, τ is stress tensor, P is pressure.

The polymer melt flow in spiral mandrel die, the changes of internal structure can cause the change of viscosity. Therefore, select Carlo model of generalized Newtonian isothermal flow as model. Carlo model uses five parameters model.

$$\frac{\eta - \eta_\infty}{\eta_0 - \eta_\infty} = \frac{1}{[1+(\lambda\gamma)^a]^{\frac{1-n}{a}}} , \tag{3}$$

where, η_0 is zero shear viscosity; η_∞ is when γ tend to be very large the polymer shears thinning reach to another equilibrium viscosity, γ is shear rate, λ is relaxation time, n as a parameter, λ and n were not changed with γ. For many polymer fluid, when γ increases to a certain degree, the macromolecular chain prone to degradation, therefore η_∞ can take zero.

If a = 1, the equation can be simplified as Cross law model. Its expression is as follows

$$\eta = \frac{\eta_0}{1+(\lambda\gamma)^m} . \tag{4}$$

When calculating, the value of n was 85000, λ was 0.2, m is cross law index, the value was 0.3.

3 Finite element simulation

3.1 MESHING

The limited release of extrusion will swell causing the surface position change, namely the die swell effect. In the die because of the internal restriction of mold wall, melt do no slip flow. After the extrusion, extrusion shape will be changed, causing the location of the free boundary changes and boundary mesh distortions. If still use the mesh form before, may affect the calculation accuracy, and even make the problem does not converge. In order to keep the grid still has good computational characteristics, need to adopt the grid replacement technology as the assistant to divide free surface mesh. When movement occurs in the free boundary, it would recalculate the distribution of nodes near the free boundary.

The grid replacement is the main method of treatment on free boundary node position, by continuously iteratively determining each node position to compose the final free surface shape.

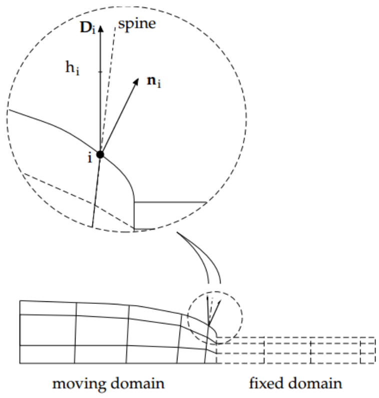

FIGURE 2 Vector relation between moving direction of free surface and other direction

The free movement of the boundary of node i can be determine by the outer normal vector n_i, direction vector D_i and the displacement of direction vector h_i, as shown in Figure 2. The outer normal vector is the vector perpendicular to the boundary. Direction vector refers to the actual direction of motion of vector node. Meanwhile, the kinematics equation set on the free boundary constrains the normal displacement of nodes and the tangential displacement of nodes. Therefore, the core content of the grid replacement technology is to adjust the boundary tangential displacement and internal node position to minimize the grid deformation. By analysing and calculate these unknown quantity, can determine the position of node movement.

Due to the symmetry of the flow channel model, when computing select the 1/2 of the channel that between the outer die body and the spiral body to mesh. Use gambit software for modelling and meshing. Considering the complexity of the melt flow in the channel, creating quadrilateral mesh structure, and in the irregular parts in the channel was divided into multiple faces, in the specified edge at the interface to do the bilateral format classification, when meshing is completed then connect the face that belong to same sub-domain.

This two-dimensional model after meshing contains 282 nodes, 332 units, which contain 102 wire unit and 230 tetrahedral elements.

3.2 BOUNDARY CONDITIONS AND PHYSICAL PARAMETERS

The boundary in the model included the flow entrance, the flow exit, the wall boundary condition, the free surface boundary conditions, the rotating boundary conditions. Among them, assuming that the fluid is stationary in the wall, that is, fluid adhere to the wall surface and don't slip at the fluid solid interface. Specify the entrance volume flow rate was 18cm^3/s. Export circumferential force was 0.

The solving order was used gambit software to pre-processing as modelling at first, then meshing, after that was sub- regional division, the die and the free surface of extrusion is divided into two independent sub region, finally specify the model boundary conditions and symmetry axis. After pre-processing the grid file were solved by polyfow software, the results were deal with flunt/post software to do post- processing.

Polyflow software provides a variety of mesh replacement method, can be applied to the 2D, 3D, blow mould extrusion and spinning of different flow problems. Here are solved by two-dimensional simulation which is more suitable for the spine, Its characteristic is the grid nodes along the spine to adjust distribution. Spinal method requires defining the initial spinal cord and the terminate spinal cord, the region that limited to use the mesh replacement method implement the normal direction slice to obtain the spinal cord for two-dimensional calculation area contains a free boundary. This method does not work on free boundary tangential adjustment, taking small amount of computation. The spinal cord is the node connecting line, does not require a straight line, as shown in Figure 3. There were one or two endpoints exist in free boundary.

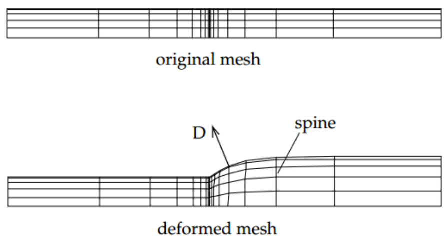

FIGURE 3 Meshing schematic by spine method

Consider a model of two spinal cord line consisting of point X_1 and X_2, when the free boundary position changed, the adjustment of internal nodes are as follow:

$$\delta x_i = w_{1i}\delta x_1 + w_{2i}\delta x_2 , \tag{5}$$

$$w_{1i} = \frac{|x_i - x_2|}{|x_2 - x_1|} , \tag{6}$$

$$w_{2i} = \frac{|x_i - x_1|}{|x_2 - x_1|} . \tag{7}$$

Among them δx is the position variable.

4 Results and discussion

4.1 PRESSURE DISTRIBUTION

Figure 4 shows the contour map of melt flow pressure after mirroring the symmetry axis. The figure shows the main pressure drop of melt in the extrusion direction close to the die head.

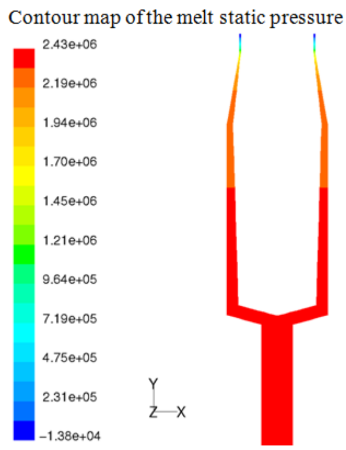

FIGURE 4 contour map of the melt static pressure

This phenomenon is mainly due to the design of spiral mandrel die flow of internal channel. In the process of melt flow, the melt flow along the helical direction in the spiral groove. At the same time by the effect of extrusion direction force and spiral tangent force, the flow resistance was large, but the volume of spiral groove in die head along the extrusion direction becomes gradually smaller, the thickness of annular gap increased larger. In the flow process the melt in the spiral groove continuous flow in the annular region. Finally, the spiral groove closed to the extrusion direction in the die head completely disappeared, the melt was extruded along the extrusion direction, at this time the pressure at the die is smaller.

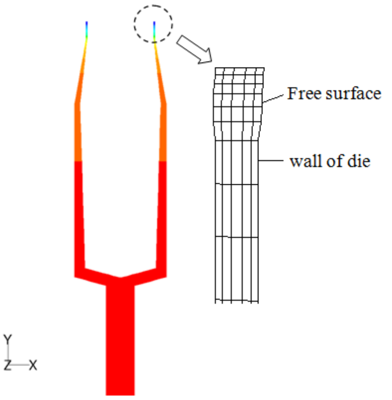

FIGURE 5 The shape of free surface in extrusion segment using the grid replacement method

Figure 5 shows when using the grid replacement method, the presentation of segment meshing of free surface and the die head exit. From the figure shows the shape of the free surface of the fluid as compared with the original shape has been changed. The extrusion segment remained 2mm thickness, but the shape of it had already apparent swell change.

4.2 EXTRUSION SWELL FLOW CHARACTERISTICS

For further study of melt viscoelasticity on outlet flow effect of extrusion swell form, requiring use the asymptotic method to analyse the model.

In the viscoelastic flow, due to the shear thinning and melt elasticity, the constitutive equations are highly nonlinear. Parameter asymptotic method is the simple and effective method to solve nonlinear problems. The parameter *We* (Weissenberg number) of viscoelastic fluid constitutive equation is the parameter to determine non-linear problem. When *We* is higher, the nonlinear will stronger. When $We = 0$, the problem degenerates into Newton fluid linear problems. A typical test result of nonlinear problems can be used as the initial value of asymptotic function equation. After iteration computing converge the problem, the non-linear parameters will be obtained [10-13].

The previous simulation has proved that the meshing of Newtonian isothermal model was reasonable. Therefore, only changes the differential viscoelastic FENE-P as a mathematical model for fluid analysis. It would obtain the effect for viscoelasticity of fluid to die swell morphology in different relaxation times near the die, as shown in Figure 6.

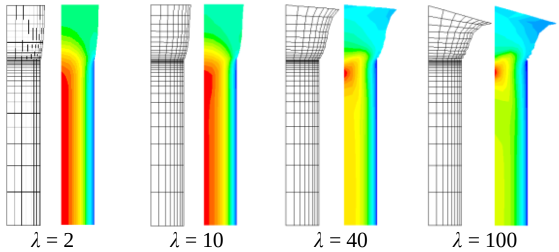

FIGURE 6 The contour map of meshing grid and Y-axis velocity in different relaxation times

For the analysis of die swell conditions in high viscoelastic state, change the relaxation time parameter in the algorithm. Draw the grid pattern of λ equal to 2, 10, 40, 100 and contour graphic of axial velocity in *Y*-axis direction. From the figure shows, when the value of λ was two, the fluid was approximated to the Newton fluid, the greater its value shows the fluid had stronger viscoelasticity. With the increased viscoelasticity of fluid, the flow state of free surface in extrusion segment had undergone significant change. The radial velocity gradient in the die decreased. Therefore, the effects of flow characteristics with viscoelasticity of different raw materials to the die extrusion segment are also different. In the film blowing process, by the blowing of wind ring and cooling control technique can ensure the forming film thickness are uniform of different raw materials.

5 Conclusion

Using the grid replacement technique to analyse the two-dimensional isothermal blown film extrusion process can simulate the swell effect of melt of extruded section, and to predict the shape changing of the free surface.

In the process of melt flow inside the die, since the volume of the spiral groove became gradually smaller, the thickness of the annular gap continuous increased, the suffered resistance of flow direction also gradually changed from spiral hoop direction to axial direction which along the extrusion direction. The melt pressure at the entrance of spiral groove was larger, then gradually became smaller along the extrusion direction, the spiral groove at the extrusion section were completely disappeared, the melt was extruded in the axial direction.

When the fluid which had strong viscoelastic was extruded, the shape of free surface in the extrusion segment would significantly change, the radial velocity gradient inside the die presented the gradual decreasing trend.

References

[1] Callari J 1991 Tight layflat offered by bubble control system *Plastics World* **49**(5) 27-8
[2] LI S, Luo J, Gao L, Mao L 2011 Study on Processing and Property of Three-layer Co-extrusion Barrier films *China Plastics* **25**(10) 20-3
[3] Qi L, Liu H, Huang X The co-extrusion technology and its application *Engineering Plastics Application* **37**(4) 83-7
[4] Zhong Y, Wang Q, Xie P, Yang W 2011 Research Progress on preparation Methods of Barrier Polymer Composites *Plastics Science And Technology* **39**(7) 103-6
[5] Wei X, Wang X, Lin H 2008 The application progress in polymer molding by Polyflow software *Shanghai Plastics* **4** 1-5

[6] Zatloukal M, Tzoganak C, Perdikoulias J Sáha P 2001 Numerical simulations of polymer flow in flat spiral dies *Polymer Engineering and Science* **41**(10) 1683-94

[7] Miao L, Zhang Y, Xue P 2010 Structure Improvement and Development of Coextrusion Dies for Multi-layer Plastics-Films *China Plastics* **24**(2) 11-20

[8] Gifford W A 2000 A three-dimensional Analysis of Coextrusion in a Single Manifold Flat Die *Polymer Engineering and Science* **40**(9) 2095-2100

[9] Ma X, Li L 2009 Numerical Simulation on Melt Flow Characteristic of Flat Spiral Type Die for Blown Film *Plastics* **38**(3) 89-91

[10] Elkoun S, Huneault M A, McCormick K, Puterbaugh F, Kale L 2005 LLDPE-Based Mono-and Multilayer Blown Films: Effect of Processing Parameters on Properties *Polymer Engineering and Science* **45**(9) 1214-20

[11] Liu X 2011 Study on Preparation of Multi-layer Co-extruded PVDF cast Composite Film *Beijng: Beijing University of Chemical Technology*

[12] Shi T, Wu D 2011 Foundation of polymer rheology *Beijing: Chemical Industry Press*

[13] Verbeeten W, Peters G W M, Baaijens F P T 2002 Viscoelastic analysis of complex polymer melt flows using the extended pom-pom model *Journal of Non-Newtonian fluid mechanics* **108**(1-3) 301-26

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