The Numerical Simulation for Extrusion Forming Process of Circular Pipe

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Abstract

The extrusion die of UHMWPE circular pipe was designed while the outer diameter was 60mm and the inner diameter was 50mm. We established the finite element model of extrusion processing for ultra-high molecular weight polyethylene (UHMWPE) circular pipe. Polyflow was used to carry out the finite element simulation of melt flow in extrusion channel. The melt velocity distribution, shear rate distribution and pressure distribution had been obtained with different geometric parameters. It had been revealed that the expansion angle of shunt had important influence on extrusion processing. The numerical simulation is beneficial to reduce the cycle of the die design.

Keywords

Circular Pipe, Extrusion Forming, Numerical Simulation.

1. Introduction

Ultra-high molecular weight polyethylene (UHMWPE) has excellent wear resistance, impact resistance, low temperature resistance, corrosion resistance and low adhesion [1, 2]. It is widely used in the military, aviation, navigation, sports equipment and many other fields. But its poor liquidity and low machining efficiency limits its application. The UHMWPE used in this paper is the modified UHMWPE, its liquidity increased significantly. The traditional design for die of extrusion molding process mainly depends on experience and the efficiency is low. We simulated the influence of the expansion angle of shunt on extrusion processing based on the rheological theory. So the efficiency of research and development of mold design will significantly improved.

Polymer melt is generally regarded as the continuous medium in the process of extrusion molding [3]. The melt in the extrusion process followed three laws, respectively for the conservation of mass, momentum conservation law, the law of conservation of energy[4].

a. Mass conservation equation

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0 \tag{1}$$

Where t represents time, ρ is density, u、v、w are respectively for the velocity vector in the x, y and z direction. The above equation can be expressed as the input mass flow rate at the unit time is equal to the rate of change of the fluid. The density is constant if the melt is incompressible in extrusion process.

b. Momentum conservation law

$$\begin{cases} \frac{\partial(\rho u)}{\partial t} + div(\rho u \mathbf{u}) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + F_x \\ \frac{\partial(\rho v)}{\partial t} + div(\rho v \mathbf{u}) = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + F_y \\ \frac{\partial(\rho w)}{\partial t} + div(\rho w \mathbf{u}) = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} + F_z \end{cases} \tag{2}$$

Where p represents the pressure on the fluid unit; τxx, τxy andτxz are the viscous stress on the fluid unit; Fx, Fy and Fz are the force on the fluid unit.

c .Energy equation

$$\frac{\partial(\rho T)}{\partial t}+\frac{\partial(\rho uT)}{\partial x}+\frac{\partial(\rho vT)}{\partial y}+\frac{\partial(\rho wT)}{\partial z}=\frac{\partial}{\partial x}\left(\frac{k}{c_p}\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{k}{c_p}\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(\frac{k}{c_p}\frac{\partial T}{\partial z}\right)+S_T \quad (3)$$

Where cp represents the specific heat of the fluid; k is the coefficient of thermal conductivity ; T is the temperature of the fluid; ST is the viscous dissipation term.

2. Establishment of the Model

2.1 Establishment of the Finite Element Model

The relationship between extrusion conditions and parameters is very complicated, in order to facilitate calculation and meet the requirements of engineering approximately, the following assumptions can be made according to the theory of polymer rheology theory and the characteristics of the extruding forming for UHMWPE [5, 6]:

a. Ignore the wall slippage, so the velocity component is zero in any direction.

b .Ignore the inertia force and gravity.

c. The fluid is isothermal flow.

d. The fluid is incompressible fluid.

The flow behavior of the melt is described by a constitutive equation [7]. The commonly used constitutive equation models mainly include Power model, law model and Bird-Carreau model. We choose the Power low model as the constitutive equation because it is simpler than other model. And we choose the modified UHMWPE as the research object. The coefficient of viscosity is 13000Pa s, relaxation time is 0.1s, non newtonian index is 0.275 [8], volume flow for entry is 5x10-6 m3/s, Picard algorithm is adopted to calculate it.

2.2 Establishment of the Geometric Model

The geometric model of extrusion runner is described as Fig. 1. It is built in Pro/E and the thickness of the pipe is 5mm, the outer diameter is 60mm, the inner diameter is 50mm. Convert the three dimensional model to stp format and import it into GAMBIT, then the model can be meshed in GAMBIT. Because of the shape of extrusion runner is symmetrical, and we take one half of it to carry on simulation analysis. The model with 40, 45, 50, 60 degree of expansion angle is simulated respectively.

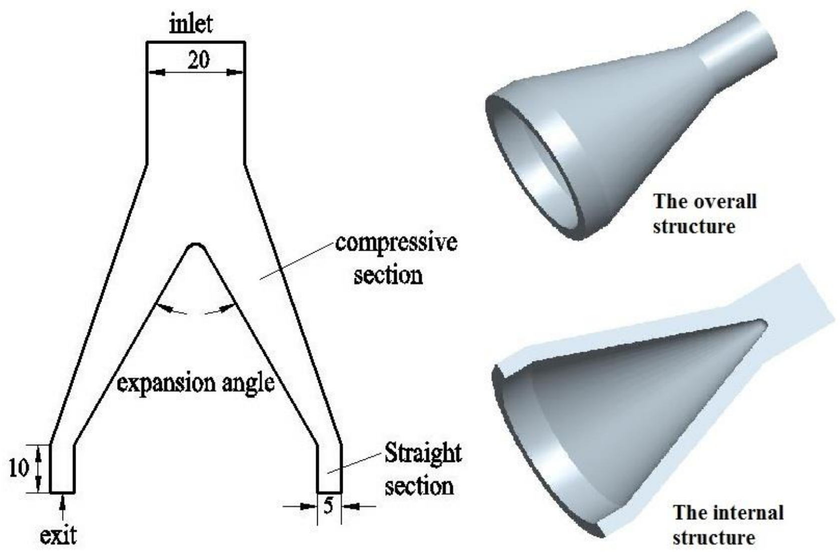

Fig. 1 Sprue runner of the Circular Pipe

3. Results and Analysis

3.1 The influence of expansion angle of diverter on extrusion pressure

The extrusion pressure, speed and shear rate of polymer melt are obtained respectively after the calculation is completed. The pressure distribution of the runner with different expansion angle was listed in figure 2. From the figure, we can see that the maximum pressure at the entrance of the channel gradually decreased with the increase of expansion angle. When the expansion angle is 40 degrees, the maximum pressure at the entrance is 6.92MPa. And the maximum inlet pressure reduced to 4.075MPa when the expansion angle is 60 degrees. This is because the runner space became bigger with the increase of expansion angle. The flow resistance of the melt decreased, and the pressure loss in the runner decreased. So the required maximum inlet pressure for the runner is low correspondingly.

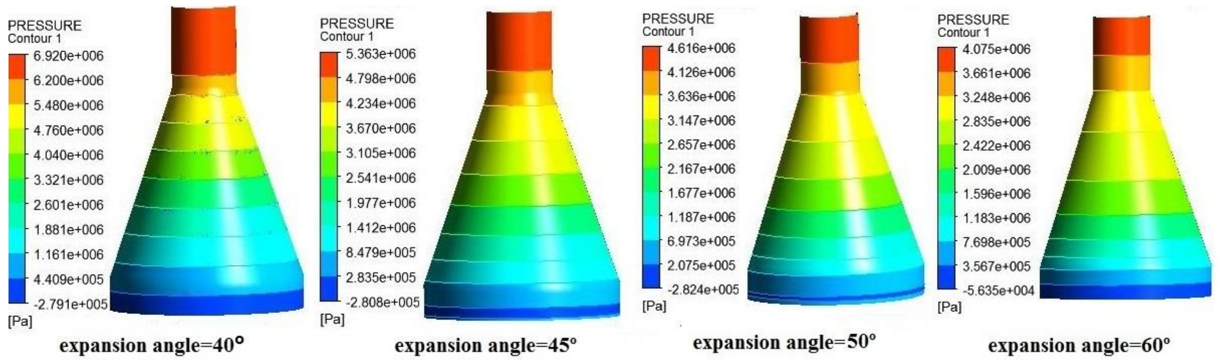

Fig. 2 The pressure distribution of the runner with different expansion angle

3.2 The influence of expansion angle of diverter on extrusion speed

The speed distribution of the runner with different expansion angle was displayed in figure3. From the figure we can know that the consistency of the exit velocity distribution becomes worse with the increase of expansion angle. It is caused by the flow resistance decreased with the expansion angle increases. Compare the speed distribution under four different expansion angle we can obtained that the melt flow is more stable when the expansion angle is 45 degrees. The speed changes of the entrance velocity decreases with the increase of the expansion angle. The reason for this is that as the expansion angle increases, the entrance channel section become larger, the compression ratio of the melt becomes smaller.

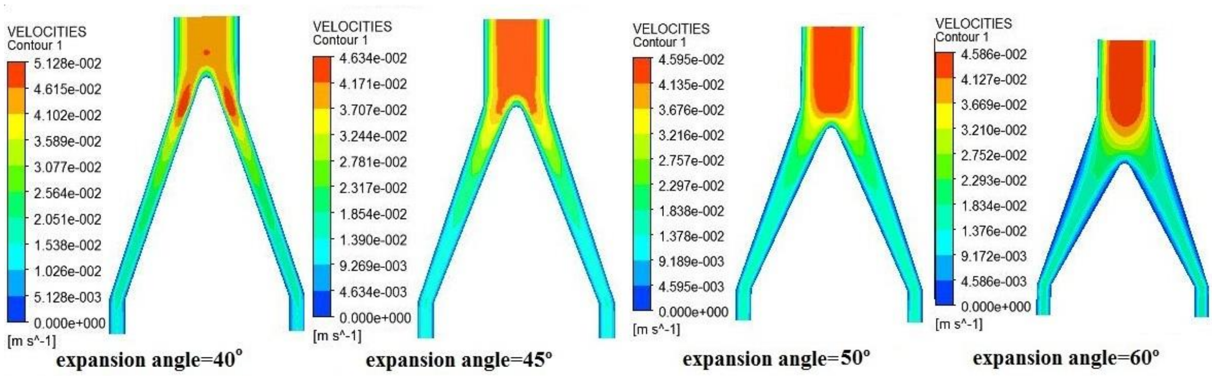

Fig. 3 The speed distribution of the runner with different expansion angle

3.3 The influence of expansion angle of diverter on the shear rate of the fluid

Figure4 show the shear rate distribution of the runner with different expansion angle. After comparison we can see that the maximum shear rate decreases rapidly and then tends to be stable with the increase of expansion angle. The shear rate is the highest at the shunt position. The expansion angle were 40 °,45 °,50 °,60 °, the maximum shear rate were 47.93 S^-1, 30.51 S^-1, 27.02 S^-1, 28.10 S^-1, which are both in the allowable range.

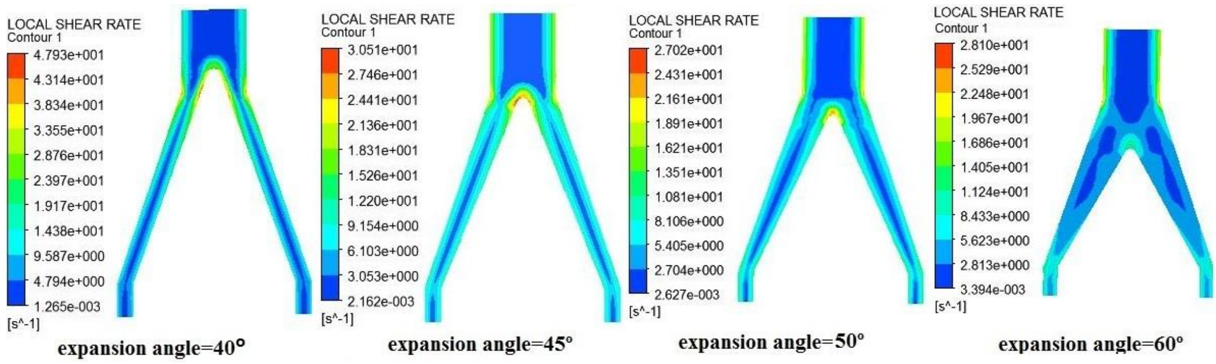

Fig. 4 The shear rate distribution of the runner with different expansion angle

4. Conclusion

In this paper, we studied the influence of expansion angle of shunt on extrusion die by Polyflow software. The pressure distribution, velocity distribution and shear rate distribution in the channel were obtained under different expansion angle. It is found that the consistency of the exit velocity distribution becomes worse with the increase of expansion angle, the pressure drop decreased, and the maximum shear rate decreases rapidly and then tends to be stable. It is analyzed comprehensively that the best expansion angle is 45 °.

Acknowledgements

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