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Flow Analysis on Solid Geometry

CAO Wei, WANG Rui, SHEN Chang-yu

(National Engineerng Reseaveh Center for Advance Polymer Processing Technology, Zhengzhou University, Zhengzhou 450002, China)

Abstract: Conventional 2.5D analysis technology which adopts the "mid-plane model" has been successful in predicting filling behavior for most plastic parts, especially for the thin shell parts. This imported model causes some inconvenience during its application. This study introduces surface model as the datum plane instead of the conventional mid-plane model and additional hot runner elements in the gapwise direction are employed to keep the flows in the surfaces at the same section coordinative. The simulations presented here are compared with the available data from Han and the short-shot experiments for rearview shell. It proves to be feasible for flow simulation on solid model in injection molding.

Key words: mid-plane model; surface model; melt front; filling factor

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0 Introduction

During the development of injection molding plastic simulation tools are used to predict die filling and the subsequent cooling of the plastic. Conventional programs use geometry representations, which describe the mid-plane surface of the real part[1]. These simulation codes are usually referred to as 2.5D. It simplifies the 3D geometry model into 2.5D mid-plane one and proceeds the simulation. After a long period of development, this technology is quite mature and stable. Now it is also good at the analytic speed and efficiency. Besides, it helps to obtain accurate results for most of the plastic parts, especially for the thin shell parts.

In the past ten years, 3D CAD systems have become widely available. However, 2.5D programs can not take advantage of these models. The effort required to generate 2.5D models from 3D models is sometimes equivalent to generating 3D information from scratch[2]. The preparation of such a mesh can take a considerable amount of time. Indeed, model preparation now represents the greatest share of time of a filling analysis.

Three primary solutions to this problem present themselves. The first is to avoid the use of the Hele-Shaw equations and to solve the governing equations in their full generality[3]. That is, provide a true 3D solution. This approach raises some significant practical problems but some progress is made. The alternative solution is to simplify the process of obtaining a mid-plane[4]. But it needs users to interact and can't be carried out automatically. Sometimes the cost is almost the same as to regenerate the mid-plane model for complicated parts. Another method is to introduce surface model as the datum plane, instead of the traditional middle-plane model and additional boundary conditions in the gapwise direction are employed to keep the flows in the surfaces at the same section coordinative[5]. It is this possibility that will occupy us in the sequel.

In current investigation, the surfaces of the solid model are meshed with triangles, and the nodes are matched into pairs along the gapwise direction. The coupling nodes are connected by an additional hot runner element (Fig.1) which permits the melt polymer flow from one node to its partner. This allows conventional method can be applied in the whole part domain. As there is no heat loses in hot runner and less flow resistance compared to surfaces, the physical values of the coupling nodes will approximately coincide. In this way, the melt front of the developed program keeps uniform during filling.

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Biography: CAO Wei (1965-), male, born in shangcheng country, Henan Province, senior engineer of Zhengzhou University, Ph.D., research interests: computer application.

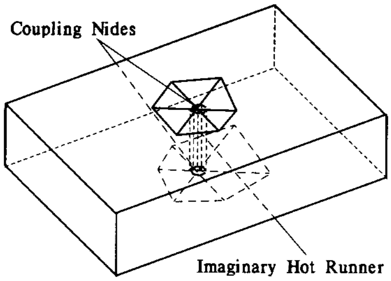


Fig.1 Schematic diagram of coupling nodes

1 Governing equations

The generalized Hele-Shaw (GHS) flow was assumed by Heber[1] for flow analysis in a thin cavity. Considering the variable density effect, governing equations for flow in the plane direction can be written as

$$\frac{\partial}{\partial x}(h\bar{u})+\frac{\partial}{\partial x}(h\bar{v})=0 \quad (1)$$

$$\frac{\partial}{\partial z}\left(\eta\frac{\partial u}{\partial z}\right)-\frac{\partial p}{\partial x}=0 \quad (2)$$

$$\frac{\partial}{\partial z}\left(\eta\frac{\partial v}{\partial z}\right)-\frac{\partial p}{\partial y}=0 \quad (3)$$

$$\rho C_p\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=k_{th}\frac{\partial^2 T}{\partial^2 z}+\eta\dot{\gamma} \quad (4)$$

Where h is the half gap, which may be a function of x and y, $(\bar{\ })$ denotes an average over z, the gapwise coordinate. ρ is the density, C_p the specific heat and k_{th} the thermal conductivity respectively. T denotes the temperature, p pressure and $\eta(\dot{\gamma},T,p)$ the sheer viscosity, where $\dot{\gamma}$ is the effective sheer rate. To effectively describe the shear thinning effect, a Cross type model is employed as follows

$$\eta(\dot{\gamma},T,p)=\frac{\eta_0(T,p)}{1+\left(\frac{\eta_0(T,p)\dot{\gamma}}{\tau^*}\right)^{1-n}} \quad (5)$$

with

$$\eta_0(T,p)=Be^{T_b/T}e^{\beta p} \quad (6)$$

Here n is the power-law index; τ^* is the stress level of the asymptotic transition region between the power-law and Newtonian fluids; and B, T_b, β are material constants.

Integrating above equations yields

$$\frac{\partial}{\partial x}\left(S\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial y}\left(S\frac{\partial p}{\partial y}\right)=0 \quad (7)$$

with

$$S=\int_0^h\frac{z^2}{\eta}dz \quad (8)$$

The governing equations for 1D runner melt flow can be written as

$$2\pi\int_0^R ru\,dr=Q \quad (9)$$

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\eta\frac{\partial u}{\partial r}\right)-\frac{\partial p}{\partial x}=0 \quad (10)$$

$$\rho C_p\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}\right)=\frac{K_{th}}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right)+\eta\left(\frac{\partial u}{\partial r}\right)^2 \quad (11)$$

Here Q is flow rate, x and r are axis and radius direction respectively, R is radius of the runner.

Similarly, we get

$$Q=\pi S\Lambda_x \quad (12)$$

with

$$S=\int_0^R\frac{r^3}{\eta}dr \quad (13)$$

The filling factor F, associated with the node and the control volume region is tracked and solved using a transport equation of the form[6]

$$\frac{\partial F}{\partial t}+u\cdot\Delta F=0 \quad (14)$$

2 Numerical method

The Equ.(7) is discreted by Galerkin method and we get

$$\sum_{l'}S^{(l')}\sum_{j=1}^{3}D_{ij}^{(l')}\cdot p_{N'}=0 \quad (15)$$

Where i, j ($j=1,2$, or 3) denote the local node numbers of the element l' corresponding to gross node N, $D_{ij}^{(l')}=\int_{A^{(l')}}(\Delta L_i^{(l')}(x,y)\cdot\Delta L_j^{(l')}(x,y))dA$ ($L_i^{(l')}(x,y)$ is shape function.

If the node connects with runner elements, the Equ.(6) should be modified as

$$\sum_{l'}S^{(l')}\sum_{j=1}^{3}D_{ij}^{(l')}\cdot p_{N'}+\sum_{l''}S^{(l'')}\sum_{j=1}^{2}R_{ij}^{(l'')}\cdot p_{N'}=0. \quad (16)$$

Here $R_{ij}^{l''}=(-1)^{i+j}\pi/4L$ (L denotes the length of a runner element).

When the pressure field is solved from Equ.(7), velocity field can be determined from the continuous equations and the temperature field can be solved with finite difference method by discreting the energy equation while the hot runner temperatures are kept constant with melt.

It is obvious that one does not have to handle the coupling nodes particularly by this scheme. They associate each other by the hot runner. When a node is filled, the melt will enter its coupling node through this imaginary hot runner in short time. Therefore, the simultaneous filling effect on the dual surfaces is achieved.

Given the solution of $F(x,t)$, we seek the next time step solution $F(x,t+\Delta t)$ through an explicit scheme. To make the solution $F(x,t+\Delta t)$ nth order accuracy, $F(x,t+\Delta t)$ is expanded in Taylor series as

$$F(x,t+\Delta t)=F(x,t)+\Delta t\frac{\partial}{\partial t}F(x,t)+(\Delta t)^2\frac{\partial^2}{2!\,\partial t^2}F(x,t)+\cdots+(\Delta t)^n\frac{\partial^n}{n!\,\partial t^n}F(x,t)+O((\Delta t)^{n+1}) \quad (17)$$

Where the appropriate time step Δt is given by[3]

$$\left((n+1)!\,\varepsilon\max\left(\left|\frac{\partial^{n+1}}{\partial t^{n+1}}F(x,t)\right|\right)^{-1}\right)^{1/(n+1)} \quad (18)$$

with ε being the fixed priori error of the scheme.

The time derivative term is determined by the following recursive form

$$\frac{\partial^p F}{\partial t^p}\,|V|=\int_{\partial V^-}\left[\frac{\partial^{p-1}F}{\partial t^{p-1}}\right]u\cdot n\,\mathrm{d}\Gamma \quad (19)$$

Where $|V|$ is the volume of the control volume with thickness, $[F]$ denotes the jump in the variable at the inter-control volume interfaces and ∂V^- is the inflow boundary of V defined by

$$\partial V^-=\{X\in\partial V;u(X)\cdot n(X)<0\} \quad (20)$$

3 Experimental and numerical results

3.1 Filling of Han experiment mold

In current investigation, we use the test mold of Han[7] and his experimental data to verify the validity of current method. The mold set consists of four cavities and circular runners of 3 mm radius, as shown in Fig.3. The material used in this experiment was PP; BJ500. The barrel temperature was set at 180 ℃ with the mold wall temperature 40 ℃. Filling time set in the machine was 1.5s. In this paper, the simulated results were obtained both for mid-plane and solid surfaces. The results are shown as Fig.3 and Fig.4.

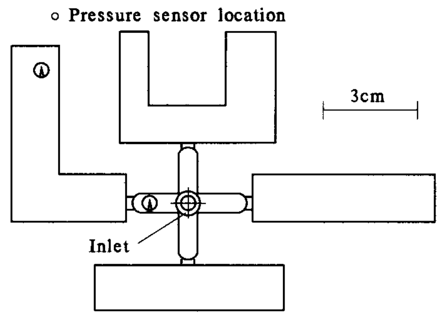
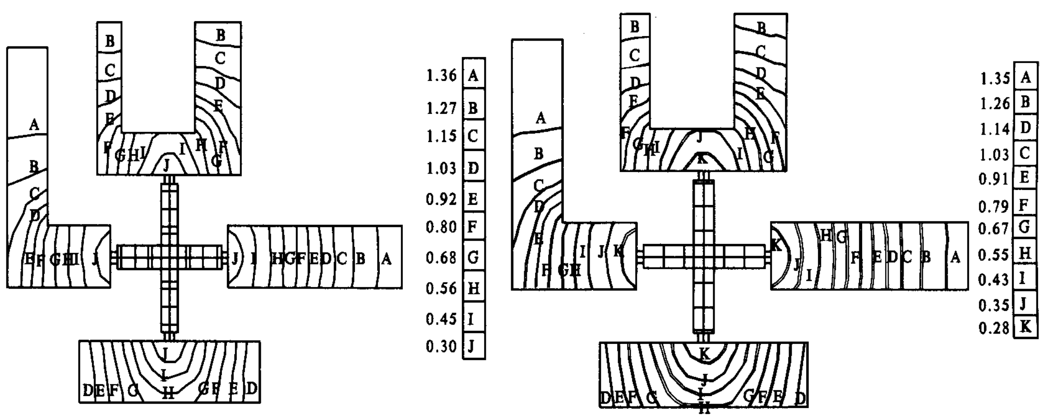


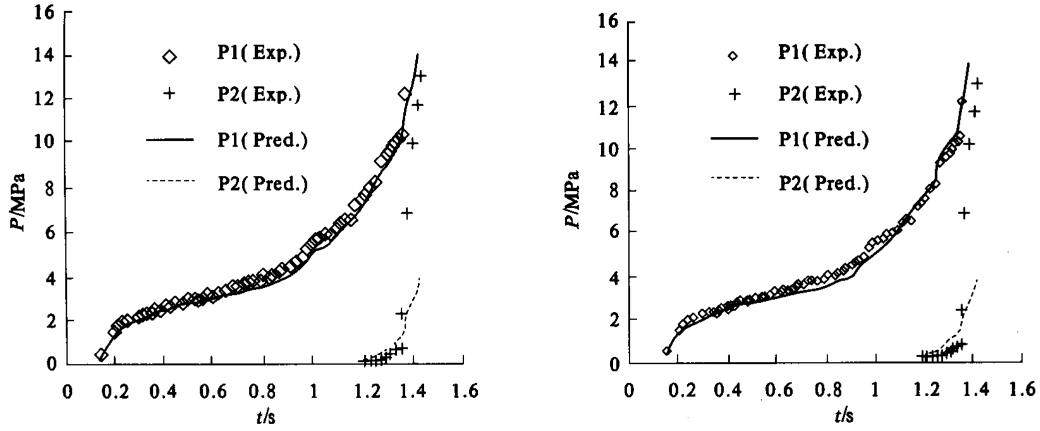
Fig.2 Schematic diagram of the mold



(a) Predicted melt front on mid-plane　　(b) Predicted melt front on solid

Fig.3 Predicted melt front

The shapes and locations on the dual surfaces of solid model are almost alike. The melt front arrives the two coupling nodes nearly simultaneously with the maximum delay 0.02 second. The melt front profile is almost identical to those from another well established analysis program, namely mid-plane simulation system taking account of the same conditions.



(a) Predicted pressures by mid-plane (b) Predicted pressures by solid method

Fig.4 Comparison of predicted and measured pressures

The pressures obtained from the program are agreeable with Han's experimental results both for solid model and mid-plane model. Because filling the imaginary runners needs additional pressure, the simulated pressure of solid model is little higher than of mid-plane.

3.2 Filling of rearview shell of Dayang motor

In this experiment, we examined the location and shape of melt front by short shot during injection. The material used in the experiment is ABS. The melt temperature is set at 200 ℃ with the mold wall temperature 50 ℃. Filling time set in the machine is 2.0s. In current investigation, the model generated from Pro/E is meshed with 5 878 elements and additional 1 430 imaginary hot runner elements. The simulation results are in agreement with the experiments. It is demonstrated by the following diagrams:

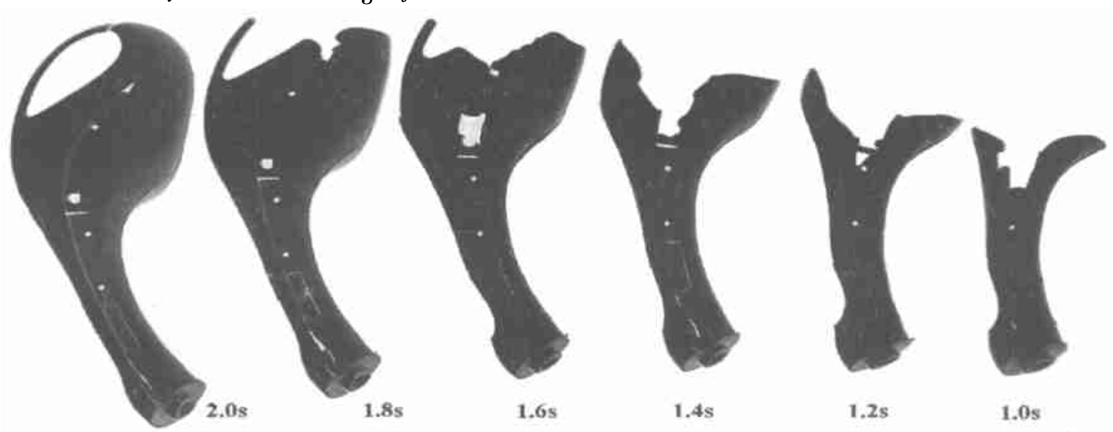


Fig.5 Evolution of short shot

Fig.6 Evolution of simulation

There is a little difference between simulation and experiment. It is due to the part's complication that the mesh can't be fine enough to depict it and induce a little amount of unmatched nodes (about 60). Another reason accounts for this little difference is that flowing through the imaginary hot runner elements needs additional time which delays the filling simulation.

4 Conclusion

This paper presents a new method to simulate the melt flow of injection molding based on 3D model by mid-plane technique. It keeps the simpleness and credibility of mid-plane and avoids the abundant calculations of full 3D. The simulation results from the developed program are in agreement with the experiments. Most importantly, it can integrate with CAD tools without fissure. Based on the comparison mentioned above, it might be fair to conclude that this method can successfully predict the flow features in injection molding and the numerical simulation system may be a useful tool for mold designers.

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实体上的流动分析

曹　伟, 王　蕊, 申长雨

(郑州大学橡塑模具国家工程研究中心, 河南 郑州 450002)

摘　要: 传统的应用"中面模型"技术的2.5维方法在预测薄壁制件成型过程中的流动行为是非常成功的, 但"中面模型"在应用过程中是非常不方便的. 通过使用实体表面作为流动平面, 在厚度方向上添加虚拟热流道来保持熔体在实体表面一致地向前充填, 并比较了模拟结果与Han的实验结果及摩托车后视镜的缺料注射结果. 算例分析表明, 这种方法对实体充填模拟是有效的.

关键词: 中面模型; 表面模型; 熔体前沿; 充填因子