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A study on gas-assisted injection molding filling simulation based on surface model of a contained circle channel part

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ABSTRACT

A practical model of cavity filling in gas-assisted injection molding (GAIM) based on the surface mode has been presented. In this model, according to the flow field at the gas front, gas penetration thickness was educed by solving the theoretical equations governing the behavior of the gas penetration through the matching asymptotic expansion method. In addition, a technology of generating gas channel mesh semi-automatically based on maximum inscribed circle of arbitrary polygon was to proposed. This method combined selecting the path of gas channel manually and calculating the parameters of gas node automatically. Finally, an experiment was employed to verify this proposed model by comparing the results of the experiment with the simulation.

1. Introduction

Gas-assisted injection molding (GAIM) is one of the innovative injection molding processes recently developed (Zhou and Li, 2003). In the gas-assisted injection molding, pressured gas displaces the polymer melt in the thicker sections of the mold cavity and leaves a polymer lay at the mold walls (Yannis and John, 2006). This new process can substantially reduce operating expenses as well as improve product quality through reduction in residual stress. Therefore, it has come into practice as a ripe technology and has been spread extensively. GAIM has mounted up to 10% of injection molding now (Zhou and Li, 2003). Despite so many advantages, the mold design and process control become more critical and difficult since this process involves dynamic interaction between two dramatically dissimilar materials flowing within complex cavities. Further, previous experience with conventional injection molding is no longer effective for this process, especially in designing the gas channel and optimizing the processing window. So the computer simulation for GAIM is needed urgently.

The injected gas typically penetrates along the path of least flow resistance (Haagh et al., 2001). In order to lead the gas to the parts in which sink marks most likely occur, GAIM products are generally designed to contain the gas channels. Among them, there are essentially two types: parts with solid thin walls reinforced with hollow ribs and those where the gas core forms a hollow interior extending throughout all or most of the part (Li et al., 2004). Four regions can be identified during gas-assisted injection molding (as shown in Fig. 1). These

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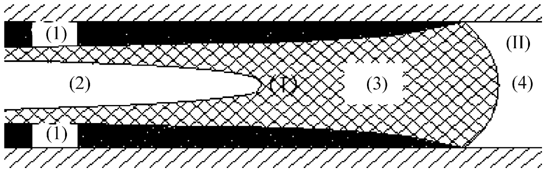

Fig. 1 – Schematic notation for flow regions and their interface in gas-assisted injection molding: (1) the solid frozen layer, (2) the penetration gas, (3) the deforming viscous melt and (4) the unfilled cavity; (I) the gas front and (II) the melt front.

four regions are confined by the melt and gas fronts. The melt front in this process is identical to that in conventional injection molding. Pressure and temperature in gas penetration region are considered the same everywhere, and the influence of gas penetration on melt flow is reflected on gas penetration interface (Zhou and Li, 2003).

During the past decades, the GAIM simulation softwares, such as Moldflow, Moldex3D, Timon et al. have been developed in international and domestic market due to the improvement of computer technique, but all of these are based on the mid-plane or 3D model. As for the mid-plane model and the corresponding gas channel, second modeling is inevitable, and it is of use only for the analysis of shell structures with cored-out ribs. With regard to the fully 3D simulation, this method needs a full-scale three-dimensional discretization of thin part, which leads to a huge amount of memory and instability of calculation. The GAIM simulation, therefore, is not applied widely in practice.

In this paper, a method of GAIM simulation based on the surface model was introduced. The surface model, comprising a certain amount of triangle elements generated by the Delaunary triangulation method based on STL, has been already applied widely in the CAE software, and the numerical solution of non-isothermal, non-Newton fluid based on surface model has been well established (Zhou and Li, 2001; Chiang et al., 1991). Additional problems of GAIM filling simulation are gas channel mesh generation and the numerical solution of gas penetration interface.

For the numerical solution of gas penetration interface, the mechanism is similar to that of the displacement of a more viscous fluid in a tube by a less viscous fluid. The residual wall thickness is determined by the capillary number $Ca = \eta U/T$. Where U is the velocity, η is the viscosity of fluid and T is the gas–liquid interfacial tension (Li et al., 2004). Many theoretical and experimental studies have been carried out to understand the physics process. Yang and Liu (1995) and Yang et al. (1996) studied the effect of the gas channel dimension on gas penetration. Huzyak and Koelling (1997) studied isothermal gas penetration of Newtonian melts in circular tubes by experiments. Poslinski experimented on the gas penetration in tubes thoroughly (Polynkin et al., 2005). Llinca and Hetu (2006) tracked the gas front and melt front using the pseudo-concentration method. Bretherton (1961) conducted analytical approximation of the governing equations for small capillary numbers, using matched asymptotic expansion method; Zhou and Li (2003) extended Bretherton's solution to higher capillary numbers using the correctional equation. For gas channel mesh, there is still lack of reasonable approach except the manual modeling. Since the pressure of gas is identical in all directions, the cross section of gas channel is usually circular (Jack, 2003). Therefore, a technology of generating gas channel mesh semi-automatically based on maximum inscribed circle of arbitrary polygon was conducted by combining selecting the path of gas channel manually and calculating the parameter of gas node automatically using gradual approximation method, which avoided the fussy second modeling.

This paper develops a practical model for simulating the filling process for the gas-assisted injection molding part with circular channels. In this model, considering the pressure of gas is identical in all directions, the cross section of gas channel is usually circular (Jack, 2003). In the Section 2 of this paper, gas penetration thickness was derived by solving the theoretical equations governing the behavior of the gas penetration through the matching asymptotic expansion method. In the Section 3, a technology of generating gas channel mesh semi-automatically based on maximum inscribed circle of arbitrary polygon was conducted, which avoided the fussy second modeling. In the Section 4, based on the derived equations and gas channel mesh, the gas front advancement is realized by the control volume method. Finally, the predicted result by this presented model was compared with experimental observation for verification.

2. Mathematical model

Since the velocity of gas penetration is lower than 70 m/s, the gas can be assumed as incompressible, and its viscosity and thermal conductivity can be neglected compared with melt. Therefore, the governing equations are

$$T = T(t), \qquad P = P(t) \tag{1}$$

That is to say, the pressure and temperature of the gas in gas channel are equal everywhere, only varying with the time.

Just like the conventional injection molding, melt flow of GAIM is considered as Hele–Shaw flow. Taking the reasonable assumptions to simplify the formulation, the governing equations are described as

$$\frac{\partial}{\partial z}\left(\eta\frac{\partial u}{\partial z}\right) - \frac{\partial P}{\partial x} = 0 \tag{2a}$$

$$\frac{\partial}{\partial z}\left(\eta\frac{\partial v}{\partial z}\right) - \frac{\partial P}{\partial y} = 0 \tag{2b}$$

$$\frac{\partial}{\partial x}(b\bar{u}) + \frac{\partial}{\partial y}(b\bar{v}) = 0 \tag{2c}$$

$$\rho C_P\left(\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right) = k\frac{\partial^2 T}{\partial z^2} + \eta\dot{\gamma}^2 \tag{2d}$$

where b is the half-gap thickness, whereas $\bar{u}$, $\bar{v}$ are the averaged velocity in whole-gap thickness in the x, y directions, in addition, P, T, t, $\dot{\gamma}$ are the pressure, temperature, time and shear rate, and η, ρ, C_P, k are the viscosity, density, specific heat and thermal conductivity of the melt, respectively.