가스사출성형에서의 가스흐름 모델 및 모델 예측

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Development of gas flow model and its predictions in gas assisted injection molding

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INTRODUCTION

Mold-design should be performed for gas to flow to the intended directions in the gas-assisted injection molding (GAIM). If gas goes in a wrong direction, many problems occur including a phenomenon called "blow through" and another phenomenon called "penetration into thin walled region". If the gas does not enter where it is expected, a problem like sink mark occurs. The control of gas direction is thus one of the most critical aspects in the application of the technology.

The rule of thumb on the direction of gas flow for GAIM has been investigated [Lim and Soh,1999; Soh, 2000; Soh and Lim, 2002; Lim and Lee, 2003; Lim, 2004a, 2004b; Lim and Hong, 2004] and simulation packages were used to verify the gas direction predicted by the rule of thumb. Lim and Soh [1999] assumed that pressure difference between a gas injection point and appropriate vent areas at both sides of well-maintained molds are equal. Consequently the pressure drops at both sides are equated to compare the resistances and to predict the gas direction. If the resistance in the sentence of "Gas goes to the direction of the least resistance" is the resistance to flow rates, this statement is not always correct. The resistance to flow rates cannot be a criterion in the prediction of gas flow direction in GAIM. Soh [2000] qualitatively treated the special case that the same resistances to flow rates for both sides resulted in the same flow rates for both sides under the geometry that two same set of two different pipes connected in series are located in parallel. Soh and Lim [2002] suggested the definition of the resistance to velocity to predict the gas-preferred direction under the simplest geometry of two different pipes connected at one connection point. However if more complicated geometries are involved, the change of velocity of melt resin becomes unavoidable. Therefore Lim and Lee[2003] established more developed-precise definition of the resistance to velocity as a rule of thumb.

Furthermore Lim[2004a, 2004b] suggested a flow model theory and its criterion under the geometry of fan-shapes between flat plates and introduced a developed flow model under the geometry of pipes in gas assisted injection molding, respectively . Lim and Hong [2004] developed the flow model under the geometry of fan-shapes between flat plates. In this paper various flow models shall be developed and analyzed to predict gas flow direction in gas assisted injection molding.

METHODS

1. Theory

The steady state flow of a pseudo plastic liquid through conduit with the radius of R is given by

$$\frac{\Delta P}{2L} = \left(\frac{Q(3n+1)}{\pi n}\right)^n \left(\frac{m}{R^{(3n+1)}}\right) \qquad (1)$$

where

m, n = power law indices
L = length of pipe in direction of flow
R = pipe radius excluding frozen layers adjacent to mold surface
ΔP = pressure drop across the distance

It is suggested that a pseudo-plastic fluid through conduit may be treated as a Newtonian fluid in such a qualitative approach as the rule of thumb to determine gas direction in GAIM. The expression of pressure drop of the steady state flow of a Newtonian liquid through a conduit with diameter of D is given in terms of average velocity V as Eq. (2) by McCabe *et al.*

$$\Delta P = \frac{32\mu VL}{D^2} \qquad (2)$$

The coated layer with the thickness of 2δ (i.e., frozen layer and hydrodynamic layer) left behind, as in Fig. 1, may be considered in the flow model when gas pushes the resin to flow forward. Since the diameter of gas channel becomes narrower due to the existence of coated layer than melt front diameter of resin pushed forward, the effective diameter of moving resin may be assumed to be the value less by 2δ than the diameter of a pipe. When mass conservation is applied and volume contraction due to compression is ignored, new balance equation may be come up with:

$$\frac{\pi}{4}D^2L(0) = \frac{\pi}{4}D^2L(t) + \frac{\pi}{4}(D^2 - (D-2\delta)^2)(L_1(t) - L_1(0)) \qquad (3)$$

Thus the length of resin may be expressed as:

$$L(t) = L(0) - \frac{4\delta}{D}\left(1 - \frac{\delta}{D}\right)(L_1(t) - L_1(0)) \qquad (4)$$

$D-2\delta$, $L(t)$ from Eq. (4) and $\frac{dL_1}{dt}$ may be substituted into Eq. (2) for D, L^* and V respectively. Then Eq. (1) becomes:

$$\Delta P = \frac{32\mu\left[L(0) - \frac{4\delta}{D}\left(1 - \frac{\delta}{D}\right)(L_1(t) - L_1(0))\right]\frac{dL_1}{dt}}{(D-2\delta)^2} \qquad (5)$$

Separating variables and integrating both sides, one may get quadratic equation in $L_1(t)$, of which the trajectory of the solution is:

$$L_1(t) = \frac{L(0) + \frac{4\delta}{D}\left(1 - \frac{\delta}{D}\right)L_1(0) - \sqrt{\left(L(0) + \frac{4\delta}{D}\left(1 - \frac{\delta}{D}\right)L_1(0)\right)^2 - \frac{8\delta}{D}\left(1 - \frac{\delta}{D}\right)f(t)}}{\frac{4\delta}{D}\left(1 - \frac{\delta}{D}\right)} \qquad (6)$$

where $$f(t) = [L(0) + \frac{4\delta}{D}(1 - \frac{\delta}{D})L_1(0)]L_1(0)) - \frac{2\delta}{D}(1 - \frac{\delta}{D})L_1{}^2(0) + \frac{\Delta Pt(D - 2\delta)^2}{32\mu}$$

On the other hand, under the geometry of fan-shaped cavity between two flat plates, the expression of melt phase flow rate may be obtained as:

$$Q = \hat{\theta}\, rH\langle v_r\rangle = 2\int_0^h v_r(r,z)\hat{\Theta}\, r\, dz = \frac{2}{3}\frac{\hat{\Theta}h^3}{\mu}\frac{P_1 - P_0}{\ln\frac{R_0}{R_1}} \tag{7}$$

where $< v_r >$: average velocity of melt phase flow

Eq. (7) may be rearranged as:

$$\Delta P_{\text{fan-plates}} = \frac{12\mu Q}{H^3\hat{\theta}}\ln\frac{R_o}{R_1} = \frac{12\mu r < V_r >}{H^2}\ln\frac{R_o}{R_1} \tag{8}$$

When mass conservation is applied and volume contraction due to compression is ignored, new balance equation may be come up with:

$$\left(\frac{R_0}{R_1}\right)^2 = \frac{1}{R_1{}^2}\left(\frac{2A}{\hat{\theta}\,\mathrm{H}} + R_1{}^2(0)\frac{2\delta}{H}\right) + 1 - \frac{2\delta}{H}$$

$$where,\ \frac{2A}{\hat{\theta}\,\mathrm{H}} = \left(R_0{}^2(0) - R_1{}^2(0)\right)$$

and δ=thickness of coated layer on one side of mold

Dynamics of R_1 (i.e., interface between gas and melt-polymer), as in Fig. 2, may be expressed as:

$$\Delta Pt = \frac{3\mu}{(\mathrm{H} - 2\delta)^2}\left[R_1{}^2(t)\ln\left(\left(\frac{2A}{\hat{\theta}\,\mathrm{H}} + R_1{}^2(0)\frac{2\delta}{H}\right)\frac{1}{R_1{}^2(t)} + (1 - \frac{2\delta}{H})\right) - R_1{}^2(0)\ln\left(\left(\frac{2A}{\hat{\theta}\,\mathrm{H}} + R_1{}^2(0)\frac{2\delta}{H}\right)\frac{1}{R_1{}^2(0)} + (1 - \frac{2\delta}{H})\right)\right]$$

$$+\frac{3\mu}{(\mathrm{H} - 2\delta)^2}\left(\frac{\frac{2A}{\hat{\theta}\,\mathrm{H}} + R_1{}^2(0)\frac{2\delta}{H}}{1 - \frac{2\delta}{H}}\right)\ln\left(\frac{(1 - \frac{2\delta}{H})R_1{}^2(t) + \frac{2A}{\hat{\theta}\,\mathrm{H}} + R_1{}^2(0)\frac{2\delta}{H}}{(1 - \frac{2\delta}{H})R_1{}^2(0) + \frac{2A}{\hat{\theta}\,\mathrm{H}} + R_1{}^2(0)\frac{2\delta}{H}}\right) \tag{9}$$

$$where,\ \frac{2A}{\hat{\theta}\,\mathrm{H}} = \left(R_0{}^2(0) - R_1{}^2(0)\right)$$

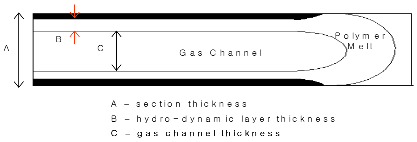

Fig. 1

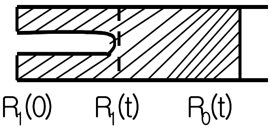

Fig. 2

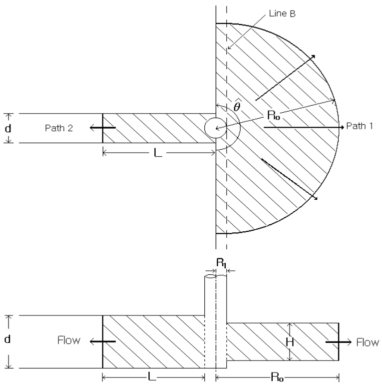

Fig. 3

2. Simulation

Figure 3 show the adopted geometry of a simple panel part with a gas channel where a pipe is connected to a fan-shaped cavity with a vertex angle of π, formed by two parallel plates and gas is injected at the part above where two cavities are connected.

RESULTS AND DISCUSSION

Figures 4(a), 4(b) and 4(c) show a simulation result of commercial software, Moldflow, its gas penetration length to both directions and a model-predictions. It is notable that the model prediction is quite consistent to the simulation result except that gas penetrates until leading melt-front reaches mold barrier,

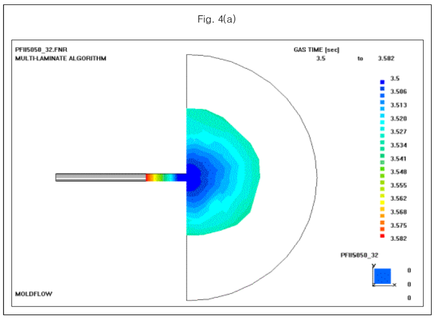
Fig. 4(a)

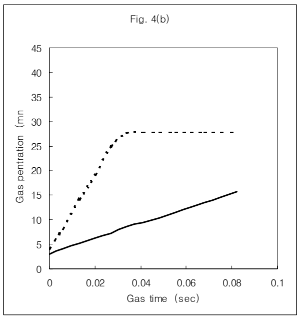
Fig. 4(b)

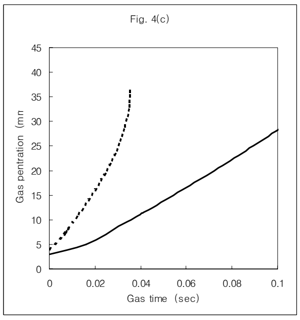
Fig. 4(c)

CONCLUSION

For various geometries including pipes and fan-shape between two flat plates, flow models suggested were quite capable of predicting the direction of gas flow in gas assisted injection molding.

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