3-D SIMULATION OF FLUID FLOW IN LOST FOAM PROCESS①

Wei Zunjie and An Geying
School of Materials Science and Engineering,
Harbin Institute of Technology, Harbin 150001, P. R. China

ABSTRACT Using Solution Algorithm- Volume of Fluid to deal with the free surface of fluid flow and the gas pressure in the gap between the molten metal and the pattern as the control factor of the filling process, the velocity profile of the molten metal when filling in a ring flange pattern during lost foam process has been numerically simulated. The results show that for both top pouring and bottom pouring, the molten metal flows forward in a circular-arc shape from the ingate and there is no any back flow or eddy flow which were often seen in green sand casting, and the farthest place of mold which is away from the ingate is the last portion for the fluid to fill.

Key words lost foam process velocity profile numerical simulation

1 INTRODUCTION

During the filling process in lost foam process, the velocity and the temperature distribution in molten metal are different from those in green sand casting[1-3]. Thus studying the characteristic of filling process in lost foam process is important to control the quality of the castings.

A computational analysis of fluid flow in the lost foam process has been reported by Wang and Paul[4], in which the metal flow velocity was assumed to be determined by the actual pattern decomposition. However, there are many parameters which influence the metal flow velocity such as the permeability of coating layer, gas-forming property of polystyrene material, and gas pressure in the gap between the molten metal flow front and the pattern. Experimental results have shown that the permeability of coating layer is one of the most important factors which influence the molten metal flow velocity in the lost foam process, especially for ferrous metals[5].

This paper studied the molten metal filling process by means of numerical simulation by coupling the momentum transfer, heat transfer and gas pressure in the gap.

2 PHYSICAL MODEL

When molten metal filling in the lost foam process, there is a gap between the metal flow front and the pattern. This gap is filled with the gaseous decomposition products which affects the fluid flow process. When the flow velocity is faster than the pattern decomposition rate, the gas pressure in the gap is increased and the flow velocity is decreased correspondingly. On the contrary, slower metal flow velocity makes the gas pressure decrease, which increases the effective metallostatic pressure head and the metal flow velocity further. Thus the influence of the permeability of the coating layer, the gas-forming property of polystyrene, the pattern decomposition rate and the metallostatic pressure head on the flow velocity could be expressed synthetically by the adjustment of the gas pressure in the gap.

3 MATHEMATICAL MODEL

3.1 Mass equation

① Received Sep. 29, 1997; accepted Feb. 4, 1998

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

3.2 Momentum equation

$$\rho_L\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial P}{\partial x}+\rho_L g_x+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right) \tag{2a}$$

$$\rho_L\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial P}{\partial y}+\rho_L g_y+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right) \tag{2b}$$

$$\rho_L\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial P}{\partial z}+\rho_L g_z+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right) \tag{2c}$$

3.3 Volume of fluid equation

$$\frac{\partial F}{\partial t}+\nabla(F\overline{V})=0 \tag{3}$$

where F is the volume of the fluid.

3.4 Energy equation

$$\rho_L C_p\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}\right)=\lambda_L\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right) \tag{4}$$

where T, ρ_L, C_p and λ_L are temperature, density, specific heat and thermal conductivity of molten metal, respectively.

3.5 Expression of gas pressure in gap

The gas pressure depends on many parameters and its expression can be written as[6]:

$$p_i=\frac{\alpha\Delta t V_p T_i(T_{i-1}-T_m)p_0}{L_p(\delta+\Delta\delta)T_m\rho_p}-\frac{KF\Delta t\,ST_i p_{i-1}(p_{i-1}+p_0)}{X_c\,\delta(\delta+\Delta\delta)T_{i-1}}+\frac{ST_i(p_{i-1}+p_0)}{(\delta+\Delta\delta)T_{i-1}} \tag{5}$$

where Δt is time step, V_p and L_p are gas-forming property and decomposition latent heat of polystyrene, respectively, δ is width of gap, S and F are area and perimeter of pattern cross section, respectively, K and X_c are permeability and thickness of coating layer, respectively.

The numerical procedure is as follows:

(a) Calculating an initial inlet velocity of ingate;

(b) Solving equation (2) for the velocity profile;

(c) Solving equation (5) for the gas pressure;

(d) Revising the velocity profile and the pressure repeatedly in order to meet equation (1);

(e) Solving equation (4) with boundary conditions for the temperature distribution;

(f) Calculating above computational steps for new time steps $(t+\Delta t)$, until the pattern is evaporated completely.

The thermophysical properties of Al-4.5Cu alloy and polystyrene pattern are summarized in Table 1.

Table 1 Thermophysical properties used in present study

Symbol	Value	Comment
$\lambda_L/(\mathrm{w\cdot m^{-1}\cdot K^{-1}})$	$818.666-0.807956T$ (775 K< $T\leqslant$911 K) $52.555+0.033T$ (911 K< T)	[7]
$C_p/(\mathrm{kJ\cdot kg^{-1}\cdot K^{-1}})$	$1.28675-2.5\times10^{-4}T$ (775 K< $T\leqslant$911 K) 1.059 (911 K< T)	[7]
$\rho_L/(\mathrm{kg\cdot m^{-3}})$	2702	[7]
$\rho_p/(\mathrm{kg\cdot m^{-3}})$	20	[8]
$L_p/(\mathrm{kg\cdot kg^{-1}})$	1003	[4]
$V_p/(\mathrm{m^3\cdot m^{-3}})$	4.1 ±0.5	[9]
$\alpha_p/(\mathrm{W\cdot m^{-2}})$	1300	[8]

The size of ring flange is d 280 mm × 50 mm, the pouring temperature is 760 ℃.

4 RESULTS AND DISCUSSION

Figs. 1 and 2 show the simulated results of three-dimensional velocity profile when filling in the lost foam process. Fig. 3 shows the simulated results of three-dimensional velocity profile when filling in the green sand mold. It is seen from these figures that the shape of the velocity profile when filling in the lost foam process is different

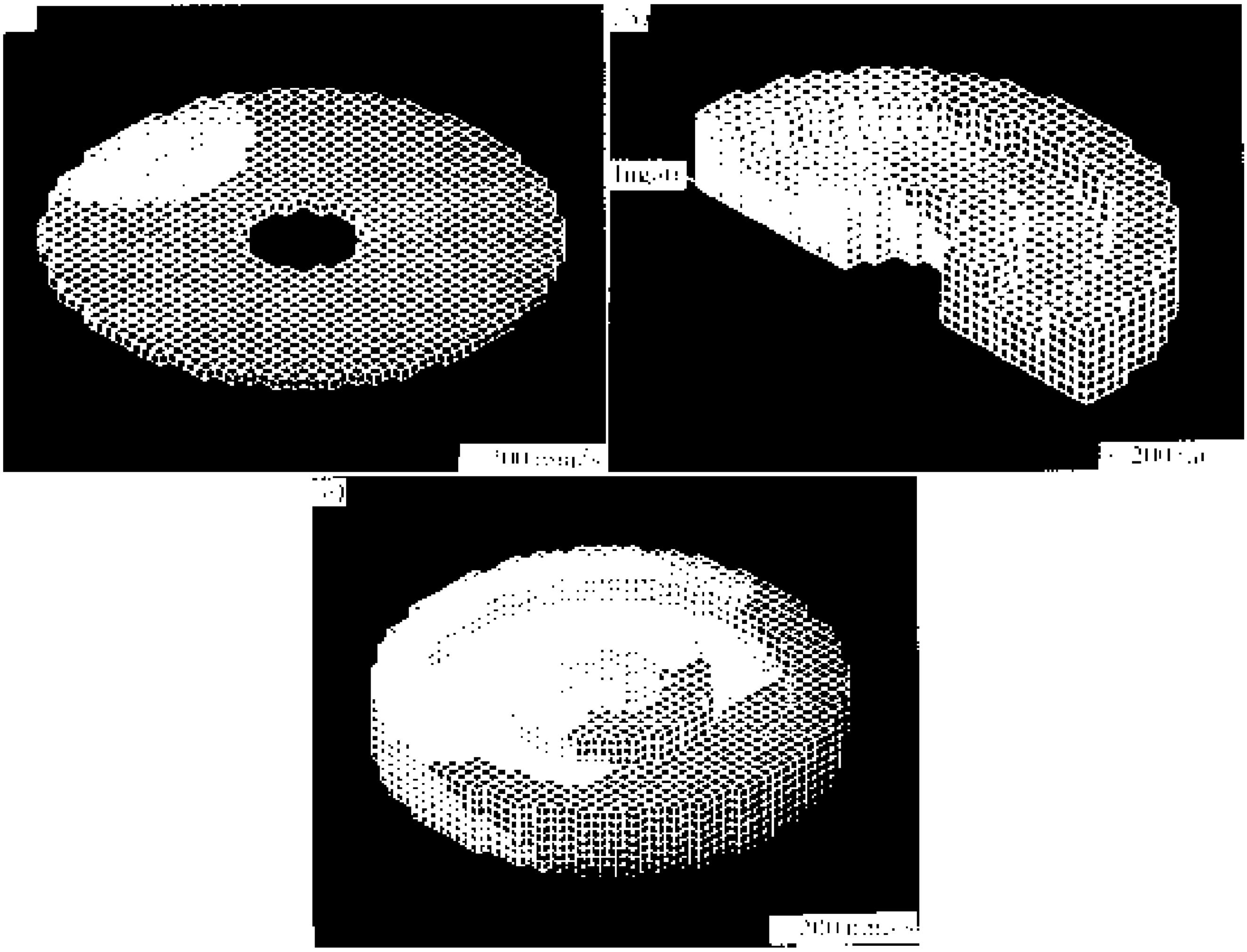

Fig. 1 Three-dimensional display of velocity profile (Bottom pouring)
(a) —Bottom plane(t = 1.50 s); (b) —Vertical plane(t = 7.51 s); (c) —t = 11.819 s

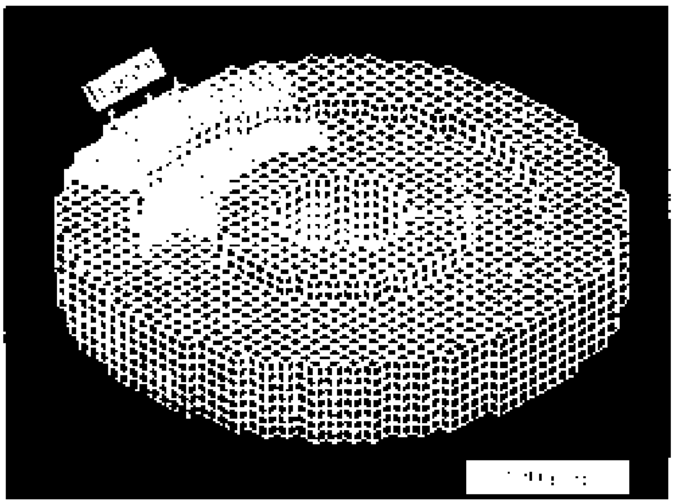

Fig. 2 Three-dimensional display of velocity profile
(Top pouring, t = 4.102 s)

from that in green sand mold.

As the gaseous decomposition products in the gap between the molten metal and the polystyrene pattern have a resistance to the fluid flow in the lost foam process, the molten metal, either top pouring or bottom pouring, flows forward in a circular-arc shape from the ingate. The simulated results show that the gravity and inertia action do not have an appreciable effect on the metal flow, the gas pressure in the gap is the main control factor of the process, which means that the parameters which influence the gas pressure in the gap such as the permeability and the thickness of the coating layer, the density and the gas-forming property of polystyrene pattern can affect the molten metal filling process significantly. Figs. 1 and 2 illustrate that the farthest place of the mold which is away from the ingate

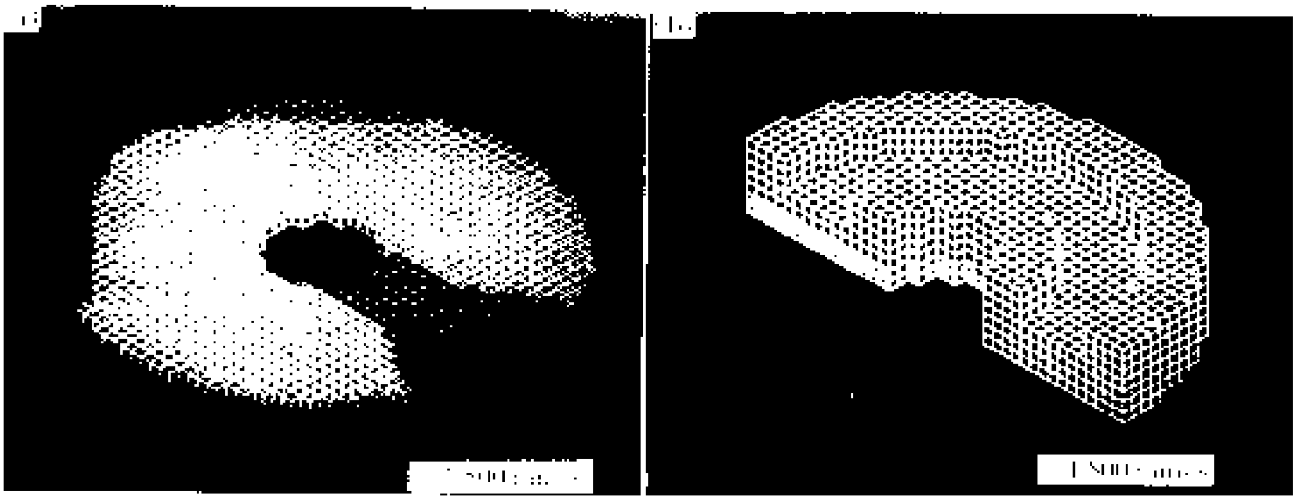

Fig. 3 Three-dimensional display when filling a green sand mold
(Bottom pouring, $t = 1.014$ s)
(a) —Bottom plane; (b) —Vertical plane

will be the last portion for the molten metal to fill, and the casting defects such as surface fold, cold shuts and inclusions are likely to form at this portion.

Filling in a green sand mold, however, is another manner, the molten metal first flow forward from the ingate at the bottom plane, after the bottom plane is fully filled, the molten metal fills from the bottom to the top of the mold layer by layer, and the last portion for the molten metal to fill is at the top of the mold.

As the free surface of the molten metal moves forward uniformly in the lost foam process, the bank or eddy flow could be avoided and this is favorable to improve the quality of the casting.

5 CONCLUSIONS

The three-dimensional velocity profile when molten metal filling in the lost foam process is numerically simulated by using Solution Algorithm– Volume of Fluid (SOLA– VOF) to deal with the free surface of fluid flow, the liquid metal flows forward in a circular-arc shape from the ingate and there is not any back flow or eddy flow. The farthest place of the mold which is away from the ingate is the last portion of the molten metal to fill, the filling process is different from that in green sand mold.

The gas pressure in the gap is the main factor which influences the fluid flow velocity, and can be used as the control element of filling process. All parameters which influence the gas pressure in the gap will significantly affect the molten metal filling process.

REFERENCES

1 Wei Zunjie and An Geying. The Chinese Journal of Nonferrous Metals, (in Chinese), 1996, 6(suppl 2): 526– 528.

2 Katashima S and Tashima S. AFS Trans, 1989, 97: 545– 552.

3 Wei Zunjie and An Geying. The Chinese Journal of Nonferrous Metals, (in Chinese), 1996, 6(suppl 2): 573– 575.

4 Wang C M and Paul A J. AFS Trans, 1993, 101: 897– 904.

5 Wu Weigang and Wei Zunjie. Metal Science and Technology, (in Chinese), 1990, 9(3): 72– 76.

6 Wei Zunjie and Li Tianxiao. Journal of Harbin Institute of Technology, 1995, 27(4): 126– 130.

7 Pehlke R D, Jeyarajan A and Wada H. National Technical Information Service, NOPB 83– 211003, 1982: 12.

8 Tsai H L and Chen T S. AFS Trans, 1988, 96: 881 – 890.

9 Shivkumar S and Callois B. AFS Trans, 1987, 95: 791– 800.

(Edited by Peng Chaoqun)