Numerical simulation of the pressure filling of an angle plate cavity

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Abstract

In this paper, a three-dimensional mathematical and numerical model of the growth of the solid metal phase within a thin-walled casting, which take into account the pressure filling process of the mould cavity with molten metal, have been proposed. In the mathematical model, velocity and pressure fields were obtained by solving the momentum equations and the continuity equation, while the thermal fields were obtained by solving the energy equation. These equations contain the turbulent viscosity which is found from k-ε model parameters by solving two additional transport equations for the turbulent kinetic energy and its rate of dissipation. In the numerical model, coupling of the thermal and fluid flow phenomena by changes in the thermophysical parameters of alloy with respect to temperature has been taken into consideration. The influence of the pressure and the temperature of metal injecting on the solid phase growth kinetics of the pressure casting were estimated. The temperature and pressure are important to the finished product quality and may be used to optimize the die casting process. The problem has been solved by the finite element method.

Keywords: Solidification process, pressure die casting, numerical simulation

1. Introduction

Casting processes are widely used to produce metal components. Much research has been devoted toward process development for the production of high quality casting goods at low costs [1]. Pressure die casting is an efficient, economical process offering a broader range of shapes and components than any other manufacturing technique. Die casting provides complex shapes within closer tolerances than many other mass production processes. Little or no machining is required and thousands of identical castings can be produced before additional tooling is required. The casting equipment and the metal dies represent large capital costs and this tends to limit the process to high volume production. Manufacture of parts using die casting is relatively simple, involving only four main steps, which keeps the incremental cost per item low. It is especially suited for a large quantity of small to medium sized castings, which is why die casting produces more castings than any other casting process [2–4]. From a macroscopic point of view, casting processes involve the coupling of solidification, heat transfer and fluid flow. Fluid flow analysis during the mould filling process has been studied vigorously in recent decades due to the advent of computer hardware systems. The filling of simple mould geometry has been previously modelled and studies for an effective filling algorithm have also been reported [5–9].

The aim of the paper is to estimate, by numerical simulation method, the effect of molten metal motion and parameters of
pouring on the thermal field and the solid phase growth kinetics, within the pressure casting of an angle plate in successive stages of its formation. The velocity field is obtained by solving the momentum and turbulent equations, whereas the thermal field is calculated by solving of the energy equation with a convection term. Coupling of the thermal and fluid flow phenomena has been taken into consideration by the changes in the thermophysical parameters of alloy with respect to the temperature. The fluid flow and thermal phenomena, which proceed in the considered metal injection system of a cold chamber pressure die casting machine, were analysed. The problem was solved by the finite element method [5-8].

2. The mathematical model of molten metal flow in the cavity of a pressure mould

The mathematical model of a molten metal flow in the filling cavity of a pressure mould has been proposed. It is based on the energy equation:

\[ \rho \left( \frac{\partial \epsilon}{\partial t} + v_j \frac{\partial \epsilon}{\partial x_j} \right) = \frac{\partial}{\partial x_j} \left( \frac{k}{\sigma_j} \frac{\partial \epsilon}{\partial x_j} \right) + c_i \frac{\partial c_i}{\partial x_j} + \frac{\partial c_i}{\partial x_j} + \frac{\partial c_i}{\partial x_j} - c_i (1 - c_i) \frac{\partial \epsilon}{\partial x_j} \]

where: \( T \) - the temperature [K], \( t \) - time [s], \( \lambda \) - the thermal conductivity coefficient [W/(mK)], \( v_j \) - the velocity vector of a molten metal flow [m/s], \( \rho_\sigma(T) \) - the density [kg/m^3], \( C_{\sigma}(T) = \rho_{\sigma} c_{\sigma} + \rho_{L} \lambda / (T_s - T_s) \) - the effective heat capacity of a mushy zone [J/(m^3 K)], \( L \) - the latent heat of solidification [J/kg], \( c_{\sigma} \) - the specific heat of the mushy zone [J/(kgK)], \( \mu_\sigma L / \rho_{\sigma} \) - the density of solid phase, liquid phase, and mushy zone, respectively [kg/m^3], \( p \) - the pressure [N/m^2], \( \mu(T) \) - the dynamical viscosity coefficient [Ns/m^2], \( g_i \) - the vector of the gravity acceleration [m/s^2], \( c \) - the specific heat [J/(kgK)], \( \mu_t \) - the turbulence dynamical viscosity coefficient [Ns/m^2], \( x \) - the coordinates of the vector of a considered node's position [m], \( k \) - the turbulence kinetic energy [m^2/s^2], \( e \) - the dissipation rate of turbulence kinetic energy [m^2/s^2], \( c_i = 0.09, c_j = 1.44, c_2 = 1.92, c_3 = 0.8, \sigma_k = 1, \sigma_t = 0.9, \sigma_e = 1.3, \sigma_p = 0.9 \) - empirical constants.

The momentum equations are closely coupled with the velocity and density constitutive relations. The following simple serial averages are adopted in this work to approximate the viscosity and density at the interface between the melt metal and the air [12]:

\[ \mu = f \mu_i + (1 - f_i) \mu_2 \]
\[ \rho = f \rho_i + (1 - f_i) \rho_2 \]

where the subscripts denote the different fluids. The fractional volume function is defined as follows:

\[ f(x_j, t) = \begin{cases} 1 & \text{for the point } (x_j, t) \text{ inside fluid 1} \\ 0 & \text{for the point } (x_j, t) \text{ inside fluid 2} \end{cases} \]

The fluid 1 is the melt metal and fluid 2 is the air. Then the interface is located within the cells where 0 < f < 1. The fractional volume function is governed by a transport equation:

\[ \frac{\partial f}{\partial t} + v_j \frac{\partial f}{\partial x_j} = 0 \]

This equation determines the movement of interface position.

The system of equations (1-6) is completed with a boundary and initial conditions for temperature and velocity or pressure fields [3-8,11,12].

3. Example of numerical calculations

The calculations were performed for the angle plate with rectangular cross-section (0.012×0.019) and height (0.072 m). The numerical calculations were made for AlSi9Cu3 alloy which poured into a steel mould. The thermophysical properties were
taken from works [11, 13]. The linear change of density ($\rho$) and thermal conductivity ($\lambda$) were assumed in $T_B$ temperature interval. The variability of the dynamical viscosity coefficient ($\mu$) with respect to temperature was determined according to the exponential relationship in range $0.003–10^5$ Ns/m$^2$.

4. Conclusions

This paper presents the coupled model of the transient evaluation of fluid flow and heat transfer during the pressure die casting process. The problem was analysed by a complex numerical model. The changes in the thermophysical parameters, with respect to temperature, were taken into consideration. It was noted that the velocity field of a liquid phase has a significant influence on the temperature field and thus the formation of the solid phase in the die casting. The results obtained with computer simulation were compared with results carried out in metal injection pressure on the real machine. A good agreement with measurements and numerical calculations was obtained.

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Fig. 3. Velocity vectors [m/s] at the time $t = 0.05$ s

References


Symulacja numeryczna wypełniania ciśnieniowego wnęki formy kątownika

Streszczenie