

NUMERICAL MODELING OF THE CAVITIES DURING THE ALLOYS SOLIDIFICATION

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ABSTRACT: The shrinkage cavity can be caused by the increase of the alloy mass density during its solidification. The associated decrease of the volume occupied by the solidifying alloy creates a pressure gradient which draws the liquid from the neighboring regions into the solidification front. In this paper we present a numerical algorithm for the shrinkage cavity simulation assuming that the liquid alloy can flow through the mushy region without any opposition. This algorithm is attached to a three-dimensional numerical model for alloy solidification using finite difference method and neglecting the alloy flow. To experimentally verify the numerical algorithm, we have chosen pure aluminium whose mushy region can be neglected and which has a great variation of density at solidification. We have used a shrinkage test piece, with cylindrical symmetry affected by a large shrinkage cavity.

KEY WORDS: Solidification, shrinkage cavity, numerical simulation, finite difference method

1. INTRODUCTION

The shrinkage cavity can be caused by the increase of the alloy mass density during its solidification. Numerical model of the volume contraction is part of the numerical model of casting, elaborated by the authors of this paper, presented in the previous papers [1-4]. The model has a high degree of generality. The problem is approached three-dimensionally taking into account the alloy flow, the thermal phenomena and the volume contraction with the formation of the shrinkages.

2. THE CHARACTERIZATION OF THE MODEL

The technological complex is defined in three-dimensional system (cylindrical or rectangular coordinates). The model takes into account several technological domains: casting-alloy (alloy in liquid phase, intermediate phase and solide phase), mould, feeder, internal chill, surface chill, and chill in mould. The model takes into account the release of the latent heat according to the lever rule and the transport of heat in technological elements takes place by conductivity, in accordance with the Fourier equation. The temperature and solid fraction are determined from the total heat balance, in which the boundary conditions are also included (Dirichlet, cauchy and Neumann conditions).

The formation and the repartition of shrinkages are obtained by the decrease of the volume of the solidified alloy that is compensated by a liquid flux. It is considered that the mushy zone does not represent an obstacle for the flow of the liquid alloy. The decrease of the volume of the solidified alloy creates a pressure gradient which propels the alloy in the neighbourhood. If the mushy zone allows the flow of the liquid alloy, then the shrinkage is formed by the descent of the free surface of the liquid alloy in contact with the mushy zone. Otherwise, in the mushy zone discontinuities are formed.

In the numerical algorithm for the simulation of the formation of the shrinkages, it is taken into account that the mushy zone allows the passage of the liquid alloy. The algorithm is attached to a numerical model for three dimensional solidification in finite difference, in which the flow of the alloy is neglected. For each time step the following operations are made:

- the identification of the cells through which the mass flux for the compensation of the volume contraction during the solidification can take place;
- the calculation of the increase of the mass in the cells with alloy in the course of the solidification; according to the mass conservation principle, the mass increase calculated in the previous step, is compensated lowering the free surface level of the liquid alloy volume in contact with the cells in the course of solidification.

3. THE TECHNOLOGICAL STRUCTURE

The study is made for spherical test (fig. 1).

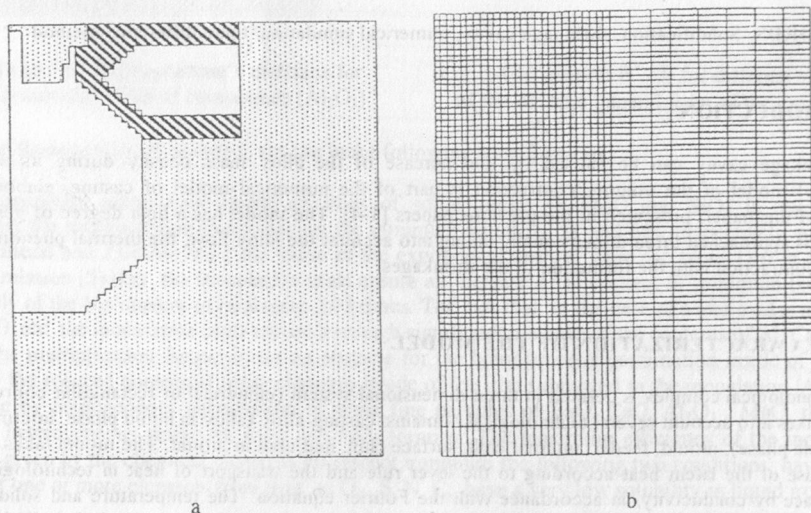


Fig. 1. The vertical section of spherical test (a) and its discretization network (b)

The analysis has been made in three-dimensional cylindrical coordinates. For the discretization we use 35 variable steps on Ox-axis, 60 steps on Oy-axis, and an angle step of $\Delta\varphi=\pi/9$. The time step is 0,02 seconds. For the experimental test we used aluminium with a negligible mushy zone and with a significant variation of the density at solidification. The pouring temperature for aluminium is 760 °C and the temperature for mould is 20 °C. The physical properties are: $\rho_{01}=2380 \text{ kg/m}^3$, $\rho_{0s}=2702 \text{ kg/m}^3$, $c_{11}=1050 \text{ J/kg grad}$, $c_{1s}=1000 \text{ J/kg grad}$, $k_{a11}=100 \text{ W/m.grad}$, $k_{a1s}=170 \text{ W/m.grad}$, $\rho_{02}=1600 \text{ kg/m}^3$, $c_{21}=1100 \text{ J/kg.grad}$, $k_{a21}=0,51 \text{ W/m.grad}$, $L=398000 \text{ J/kg}$.

4. THE ANALYSIS OF THE MODELING RESULTS AND THE COMPARISON WITH EXPERIMENTAL DATA

Figure 2 presents the evolution of the solidification front and the forming of the shrinkage for the numerical simulation and the experimental and numerical results are presented in table 1.

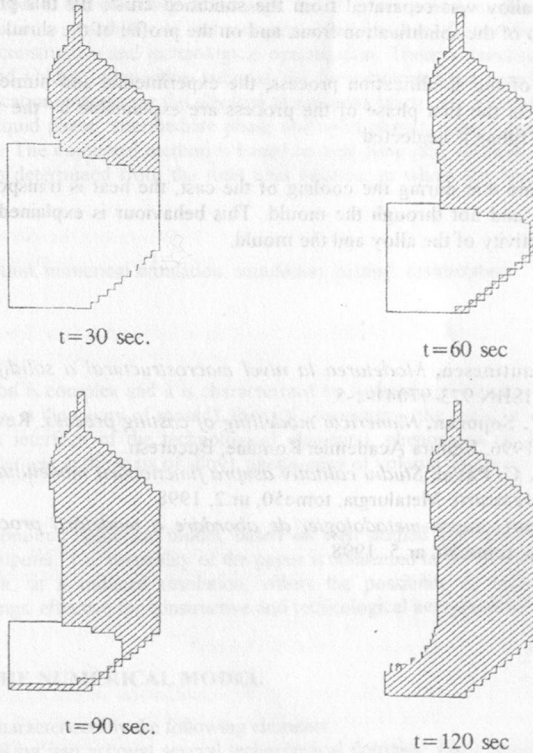


Fig. 2. The solidification front and the profile of the shrinkage

Table 1. The comparison of experimental and numerical results

No	Analysed parameter	Experimental result	Numerical result
1.	Solidification time, sec	215	207
2.	The height of the superior solidified part after 30 sec, mm	34	50
3.	The height of the superior solidified part after 60 sec, mm	57	65
4.	The height of the superior solidified part after 90 sec, mm	67	75
5.	The height of the superior solidified part after 120 sec.	Ful casting	Ful casting

The experiment was made using aluminium for the casting of a spherical test in a green sand mould with a ring of steel at the top. The time of filling was 10 sec and it was neglected. After 30, 60, 90 sec the mould was destroyed, the unsolidified alloy was separated from the solidified crust. By this procedure we obtain the information on the evolution of the solidification front, and on the profile of the shrinkage during its formation.

Excepting the initial phase of the solidification process, the experimental and numerical results are in good agreement. The differences in the first phase of the process are explainable by the fact that the flow of the liquid alloy during the mold filling is neglected.

The numerical results indicate that during the cooling of the cast, the heat is transported mainly through the solidified parts of the alloy and not through the mould. This behaviour is explained by the great difference between the thermal conductivity of the alloy and the mould.

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