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A numerical simulation of the DC continuous casting using average heat capacity

Abdel Illah Nabil Korti and Yahia Khadraoui

Faculté des Sciences de l'Ingénieur, Département de Mécanique, Université de Tlemcen, B. P. 230, Tlemcen 13000, Algérie

Continuous casting is one of the prominent methods of production of metals. The effective design and operation of continuous casting machines needs complete analysis of the continuous casting process. In this paper, a finite volume model has been developed and applied to compute the fluid flow, temperature and flux distributions within the liquid, mushy and solid zones in the mold and cooling regions of an aluminum alloy direct-chill continuous casting machine. The average heat capacity method was successfully implemented for the analysis of conjugate heat transfer during the phase change phenomenon. The effect of phase change on convection is accounted for using a new modification in the velocity vector. The effect of casting speed on fluid flow, temperature and surface heat flux evolution was investigated. The predicted temperature distribution and surface heat flux were compared with experimental measurements and numerical solutions given in the literature. A reasonable agreement was obtained.

Key words: continuous casting, finite volume, fluid flow, heat transfer, solidification.

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The heat transfer and fluid flow mechanism involving phase change problems are of a great complexity due to the nonlinear nature of the governing equations. Several analytical techniques have been developed and employed for solid-liquid phase change problems to acquire approximate solutions. These include: heat balance integral [1], variational [2], embedding [3], isothermal migration [4] and source and sink [5] methods. A common drawback of these approximation techniques, however, is that they either are limited to one-dimensional analysis or result in very complicated formulations when applied to multidimensional problems.

Many numerical methods, like finite difference [6, 7] or finite volume [8] or finite element [9, 10] appear to be more practical in solving the phase change problems. A review of the available literature reveals that the numerical techniques applied for solving the thermal transport phenomena during the solidification processing of materials can be broadly classified into two distinct categories, namely, a single-domain approach and a multidomain approach. The multidomain method applies the governing equations separately for each phase and specifies the proper coupling boundary conditions between the phases. The position of the interface is a priori unknown and must be determined explicitly as part of the solution. Thus, the phase change interface is continuously traced such that the mesh is coincident with the moving phase change boundary. These methods often offer good accuracy, but the high cost of these methods in terms of computational effort and storage has limited them to simpler problems [11, 12]. In the single-domain methods, the mesh remains fixed and the energy equation for the liquid and solid domains are solved simultaneously despite the temperature gradient discontinuity at any point of the interface. The advantages of these methods are their simplicity and ease with which they can be extended to three-dimensional problems. Based on the modeling of latent heat transfer, the single-domain methods are classified mainly into enthalpy and heat capacity methods.

The enthalpy model either treats the enthalpy as a dependent variable in addition to the temperature [13] or constructs a latent heat flow vector, with the use of enthalpy of the system, through a volumetric integration [14]. The heat capacity method introduces the latent heat effect onto the heat capacity of the material over the phase-transition temperature interval [15, 16]. Of the procedures presented, the technique of Hsiao [17] is attractive because both zero and large temperature intervals in the mushy zone can be simulated. Generally,