SIMULATION OF PHASE TRANSITIONS DURING CONTINUOUS CASTING

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Abstract

This work simulates the process of continuous casting of a metal rod from a melted state. The model includes the phase transition from melt to solid, both in terms of latent heat and the varying physical properties.

Key words: continuous casting, phase change, latent heat.

Introduction

Metal casting plays an important role in production because it determines the quality of finished products.

There are several problems during solidification of metals in the manufacturing process.

Defects such as cracks are usually formed during the process of metal crystallization. They are divided into internal and surface. Surface cracks are classified into transverse and longitudinal. Formation of transverse cracks is a consequence of metals going into recesses in the walls of the mold.

Longitudinal cracks are formed in two cases. First, layer offsets of the ingot occur during crystallization. It creates tangential stresses which create this defect. Secondly, metal poured into a mold is covered by a thin solid crust at the initial time. The following metal creates pressure on this crust. This is the cause of the defect.

Experimental method requires huge expenses and complicated equipment in solving such problems.

Modern development of mathematical modeling makes it the most attractive approach to solving the problems in casting.

Description of continuous casting machine

Continuous casting machine [3] used to study the solidification process is shown in Figure 1.

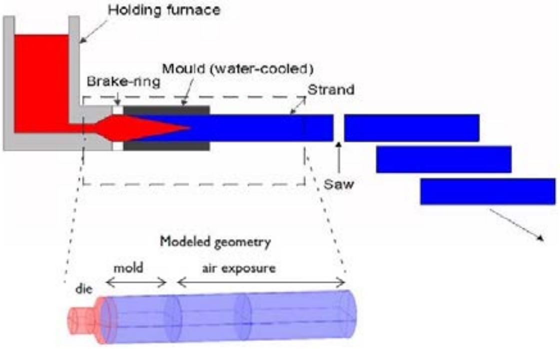

Figure 1. Continuous casting machine

The installation consists of such elements as:

- holding furnace;
- casting mold with water cooling;
- brake ring;
- pulling vise;
- cutting device;

Mathematical model

The process operates at steady state, because it is a continuous process. The heat transport is described by the equation:

$$\nabla\cdot\left(-k\nabla T\right)=Q-\left(\rho C_p\mathbf{u}\cdot\nabla T\right) \quad ,$$

where k - thermal conductivity
Cp - specific heat
Q - heating power.

During the phase transition, a significant amount of latent heat is released. The total amount of heat released per unit mass of alloy during the transition is given by the change in enthalpy, Δ*H.* In addition, the specific heat capacity, *Cp*, also changes considerably during the transition. As opposed to pure metals, an alloy generally undergoes a broad temperature transition zone, over several Kelvin, in which a mixture of both solid and molten material co-exists in a "mushy" zone. To account for the latent heat related to the phase transition, replace *Cp* in the heat equation with (*Cp* + δΔ*H*), where Δ*H* is the latent heat of the transition, and δ is a Gaussian curve given by

$$\delta=\frac{\exp(-\frac{\left(T-T_m\right)^2}{(\Delta T)^2})}{\Delta T\,\mathrm{C}\sqrt{\pi}}.$$

Here *T*m is the melting point and Δ*T* denotes the half-width of the curve, in this case set to 5 K, representing half of the transition temperature span.

The change in specific heat can be approximated by:

$$\Delta C_p=\frac{\Delta H\cdot H}{T_m}$$

Here H is the smooth Heaviside step function.

Here the laminar flow is simulated using the Weakly Compressible Navier-Stokes application mode. The application mode describes the fluid velocity, **u**, and the pressure, *p*, according to the Navier-Stokes equations:

$$\rho\frac{\partial\mathbf{u}}{\partial t}+\rho\mathbf{u}\cdot\nabla\mathbf{u}=\nabla\cdot[-p\mathbf{I}+\eta(\nabla\mathbf{u}+(\nabla\mathbf{u})^T)$$

$$-(\frac{2\eta}{3}-k)(\nabla\mathbf{u})\mathbf{I}]+\mathbf{F},$$

$$\frac{\partial\rho}{\partial t}+\nabla\cdot(p\mathbf{u})=0$$

where ρ is the density (in this case constant), η is the viscosity, and κ is the dilatational viscosity (here assumed to be zero).

Problem-solving procedure

We can use analytical and numerical methods for finding solutions, but an analytical solution is a tedious task.

For solving nonlinear differential equations numerical methods can be used. Particularly, such as:

1) finite difference method;
2) variable separation method;
3) finite element method.

Finite difference method is a commonly known and simple method of interpolation. Its essence is replacing the coefficients of the differential equations with the difference coefficients. It allows boiling the solution of differential equation down to one of its difference analogues that is to build its finite-difference scheme.

Variable separation method is one of the most common and effective methods of solving differential equations. This method has other names: the Fourier method or the eigenfunction method. The main idea of this method is that the solution of Partial Differential Equations (PDEs) is boiled down to the solution of Ordinary Differential Equations.

Finite element method is a method based on discretization of the universe of discourse into small parts of regular shape (finite elements). Nodes establish a link between adjacent elements. They present the target function as a simple expression within the cell. The essence of finite element method is that the differential equations are replaced with a system of algebraic equations. Finite element method was chosen to solve this problem.

Nowadays a series of software products in which the finite element method is implemented (ANSYS, MSC.Nastran, ABAQUS, Impact, COMSOL Multiphysics, and others) are developed. Comsol Multiphysics software package allows to simulate the dynamics of thermal processes in continuous casting machines.

Discussion of results

Calculations were carried out at change of casting speed of v_{cast} = 0.003 m / s to v_{cast} = 0.0001 m / s. Temperature distribution at different casting speeds is shown in Figures 2 and 3.

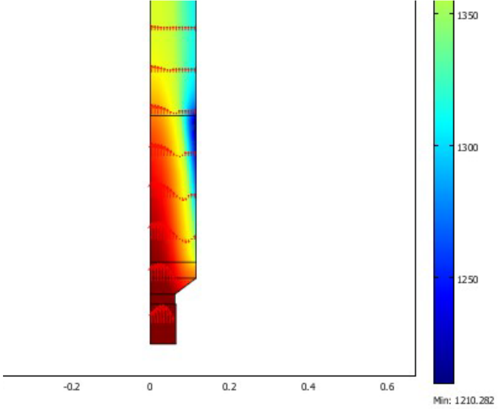

Figure 2. Temperature distribution at the casting speed of 3 mm / s

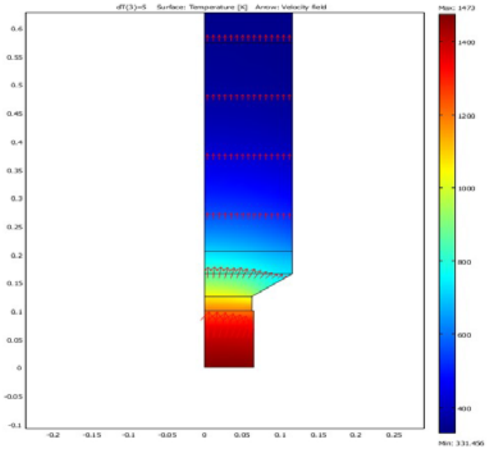

Figure 3. Temperature distribution at the casting speed of 0.1 mm / s

At the speed of 0.0001 m/s solidification occurs at the inlet of the form (cork is formed). Casting with defects is formed when the speed is more than 0.001 m/s. Defects increase with increasing temperature. As the result of the research, the most suitable casting speed is v_{cast} = 0.0016 m / s. For small deviations from the casting speed the defect formation did not occur.

Based on the results we can conclude that the model is sensitive to the change of casting speed.

Conclusion

The construction of physical models is based on profound theoretical knowledge in the subject field. Modeling is very important to solve engineering problems, because it can reduce development time and avoid experiments that are too difficult or expensive to make in real life. Therefore, the use of COMSOL Multiphysics software package requires a thorough study of many mathematical methods whose implementation leads to visible results.

As a prospect to enhance the model we plan to develop technological modes to melt metals into more intricate shapes, such as three-dimensional ones. It is also planned to make a multi-metal simulation.

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