Numerical simulation of conduction refining of molten aluminum in the casting launder

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In the paper numerical modeling of the process of conduction refining in the casting launder is carried out. The behavior of non-conductive particles in aluminum melt during conduction refining is investigated. Numerical calculation is performed using the MAXWELL and FLUENT software packages. For calculation of non-conductive particle trajectories and distributions the Discrete Phase Model is used. It is shown that electromagnetic forces strong affect the process of particle migration to the surface. The effective current value for refining the melt in the casting launder is determined.

Keywords — refining, solid inclusions, Euler-Lagrange

I. INTRODUCTION

Currently, the scope of metallurgical products is expanding rapidly. In particular, this applies to aluminum alloys, which today are widely used in aircraft manufacturing, shipbuilding and additive technologies [1]. Moreover, one of the most important stages in the production of aluminum ingots is the refining operation, the purpose of which is to remove unwanted gas and solid impurities from the melt [2].

One of the promising methods for refining aluminum melt is conductive refining by electric current. Significant advantages of this technology include the absence of rotating mechanisms for gas dispersion, the possibility of refining directly in the casting launder, as well as additional heating, which is important during melt transportation.

II. NUMERICAL MODELING

A. Numerical considirations

The problem of conductive refining is a type of the problem of magnetohydrodynamics and currently requires the approach of combining several software packages for numerical simulation [3]. In this work, for the numerical simulation, the combination of the MAXWELL and FLUENT software systems is used.

MAXWELL is a finite element product and is designed to solve the problems of electrodynamics in the Coulomb gauge. FLUENT is based on the finite volume method and allows solving heat and mass transfer problems, including multiphase flows. To set the source terms from in FLUENT, file-based transfer and interpolation of the distribution of electromagnetic forces and Joule heat are performed

B. Equations

The electromagnetic field in the computational domain is described by the Laplace equation for the vector magnetic potential [4]. At the boundary of the computational domain, the Dirichlet condition for the normal component of the vector potential and the Neumann condition for the tangential component [5] are applied.

Heat and mass transfer processes in the melt are described by the equations of motion, continuity and energy for an incompressible fluid [6]. In this paper, we use the SST model to describe turbulence [7]. The Boussinesq-Oberbek approximation [8] is also used for modeling convective flows.

The motion of the discrete phase is described using the Lagrange equation [9]. The model takes into account buoyancy force, drag force, virtual mass force, lift force and also electromagnetic force. Drag force is calculated using the Chiller-Naumann approximation [10]. Lift force is determined based on the Saffman-Mei model [11]. The electromagnetic force acting on a particle is determined based on the Leenov and Kolin model [12].

III. RESULTS AND DISSCUSSION

A. Electromagnetic force distribution

Figure 1 shows the vector distribution of electromagnetic forces in the longitudinal section of the melt. Based on the distribution of electromagnetic forces the melt region can be divided into three zones. First zone is area of the absence of MHD effects. It is the input part of the launder, which also includes a section of the contact of the melt with the electrode. In this zone, the current density is minimal, and, therefore, transit flow expected along the length of the launder in this zone, which is determined by the mass flow rate.

Second zone is area of vortex flows. It is the region located between the zone of the absence of electromagnetic forces and the zone where their distribution has a uniform radial character. Since in this zone the distribution of electromagnetic forces along the length and radius is nonuniformity, the rotor of the field of electromagnetic forces is nonzero. Thus, in this zone, eddy recirculated flows are expected.

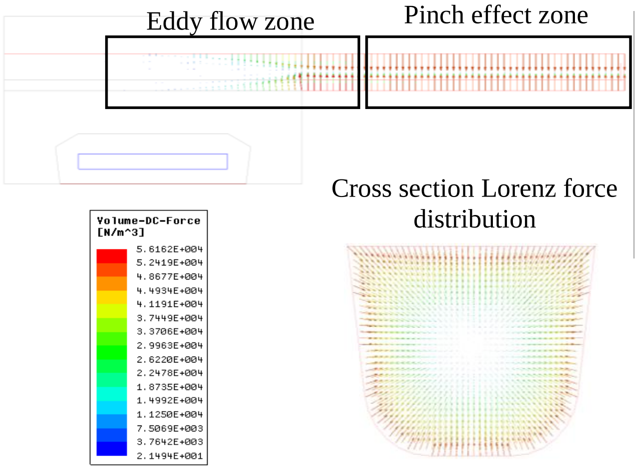

Fig. 1. Lorenz force distribution

The third area is the pinch effect zone. Unlike the second zone, in this area the distribution of electromagnetic forces is uniform in which the radial component of the forces prevails, as shown in Figure 8. However, since the cross-section of the channel has a complex shape, rotational flows are expected in this plane. Also in this zone, the potential part of the electromagnetic force expressed by electromagnetic pressure, compressing the melt in the radial direction.

B. Mass transfer in the melt

Figure 2 shows the vector distribution of the velocity field in the melt at a current of 1000 A. As expected from the distribution of electromagnetic forces, vortex flows are formed in the region of the electrodes. In the cross-section of the melt, a rotational movement of the melt is created, as figure. 3 shows. Figure 3 also shows that the rotational movement changes direction in the middle zone of the launder.

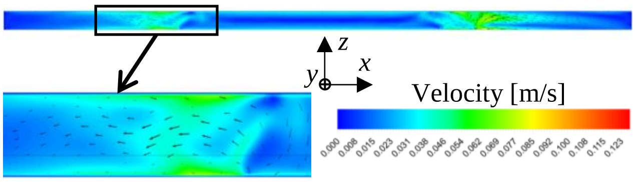

Fig. 2. Velocity field distribution

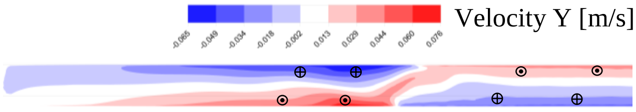

Fig. 3. Y component of velocity field distribution

The magnitude of the melt velocities in the launder has the range of 1-7 cm /s. A further increase of the integral current in the metal leads to more intense flows, especially in the region of the metal surface. More intense currents can lead to oxide film damage and its further stirring into the melt.

C. Transport of particle inclusions

Figure 4 shows the distribution of a cloud of non-conducting particles in the melt. Particles enter the entrance zone under the influence of a low-intensity transit flow. Under the action of the transit flow, particles migrate through the launder into the region of vortex flows and are involved in the flow.

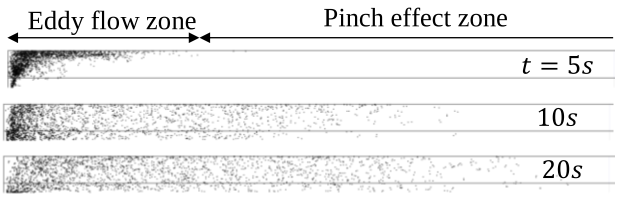

Fig. 4. Particle cloud distribution (particle diameter $20\mu m$)

Further particles migrate to the area of action of electromagnetic forces and accumulate on the walls of the launder. The electromagnetic force acting on the particles plays the main role in the accumulation of particles on the walls.

IV. CONCLUSSION

A numerical simulation of the process of melt conductive refining from non-metallic inclusions is carried out.

The pattern of the melt flows in the launder is determined under the influence of electromagnetic forces arising from the flow of electric current.

Non-conducting particles distribution in the melt and the zones of particle accumulation under the influence of electromagnetic forces are determined.

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