NUMERICAL SIMULATION OF METAL-BATH MOTION IN AN ALUMINUM REDUTION CELL

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Introduction. 3D mathematical models for different processes in an aluminum reduction cell have been developed. Each of the models can calculate the field of some physical parameter (e.g., flow velocity) using, as an input, fields of other parameters (current density and magnetic induction) or boundary conditions (ledge profile) produced by other models. In this study all models have been worked out to run simultaneously except for the calculation of magnetic field, which is assumed to be stationary. Natural convection is taken into account in the conjugate heat transfer problem. The proposed hydrodynamic criterion for the metal-bath disturbance level seems to be useful in solving the MHD-stability problem.

1. Main processes. Physical-chemical processes that proceed in an electrolytic cell are complicated and difficult for mathematical modeling. It is caused by their strong interference, on the one hand, and their transient three-dimensional nature, on the other. For example, the distribution of the current density depends on the distortion of the bath/metal interface and the shape of the ledge that, in their turn, depend on the temperature distribution, the latter relies on the current density, materials conductivity and flow velocities inside and around the cell, etc. Moreover, some of the processes are not entirely investigated from the scientific point of view. That is why, for engineering calculations, approximate mathematical models were used that not fully took into account the interference of the cell processes [1, 2, 3] or used two-dimensional approximations of the spatial problems.

2. Computation strategy. However, recently developed approximate methods have their own important advantages. First of all it is the short time of calculations that gives the possibility to analyze and compare many variants. Secondly, it is the use of relatively simple mathematical models that allow easy processing of the results and quick mistake finding if any happens. Besides, the isolation of the models permits to change the boundary conditions, material properties, etc., independently. As a result, a variant of computational procedure is chosen that can combine the completeness of the model with flexibility and rapidity of convergence of it parts.

While solving the full problem, one must compute at any time step the following 3D variables: current density, magnetic induction, temperature, flow velocities inside and outside the reduction cell, concentrations of chemical species, pressure, stresses and deformations in the solids, changes in material properties and also the position of the bath/metal interface and the shape of the ledge. For the calculation any of the main dependent variables we suggest to construct a separate (local) mathematical model or (for the flexibility) the set of models with different level of detail of the process. The computation of the whole model will consist of simultaneous local model calculations plus data transfer between these computational processes. To simplify the transfer, a unified computation grid is used. In

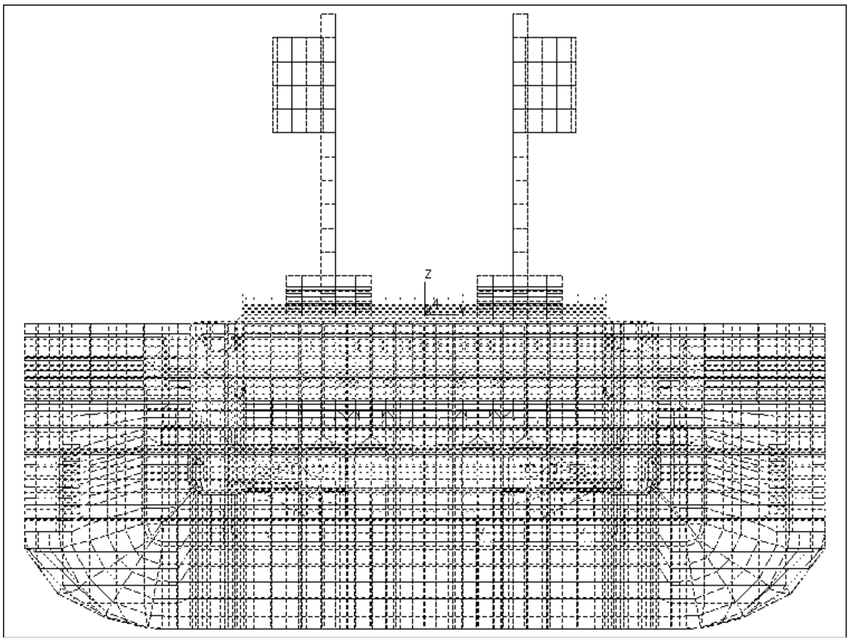


Fig. 1. Cross-section of the lower part.

other words the main model computation is carried out on the unified grid using splitting the whole problem into separate physical processes. This strategy permits to calculate each physical process using its own mathematical model on the individual processor. Actually that means parallelization of the computing algorithm. Furthermore, this approach has the advantage allowing to use the already created computer codes.

3. Mesh creation. The computational mesh, which is built up for the whole reduction cell, must meet the requirements of all computer codes that are going to be used: ANSYS, STAR-CD and BLUMS, in our case. The whole mesh consists of two parts. The upper part contains an operating zone and a manifold beam, the lower part embraces the bath itself and the surrounding air (Fig. 1).

4. Calculations of the main parameters. Because of the importance of that parameter and its great influence on the other parameters the calculation of the current density is carried out using all three computer codes: ANSYS, STAR-CD and BLUMS. The obtained fields are compared to check out all possible mistakes and to control calculation accuracy. The algorithm requires calculating the electric potential first. The Poisson's equation with the source term in the right part is numerically solved. The side ledge shape and the form of the bath/metal interface are needed to set the boundary conditions. Flow velocities inside the cell are used as an input to calculate the source term. Current density is calculated after obtaining the electric potential field. Conjugate heat transfer problem is to be solved to find a thermal balance of the cell. The task becomes complicated because of the flow inside the bath and natural convection around the housing. Current densities, the form of the bath/metal interface and the flow velocity field inside the bath are required as an input. The vector field of flow velocities in the surrounding cooling air is shown in Fig. 2. The central vertical section of the cell is shown. The temperature of the air far from cell is assumed to be 20°C.

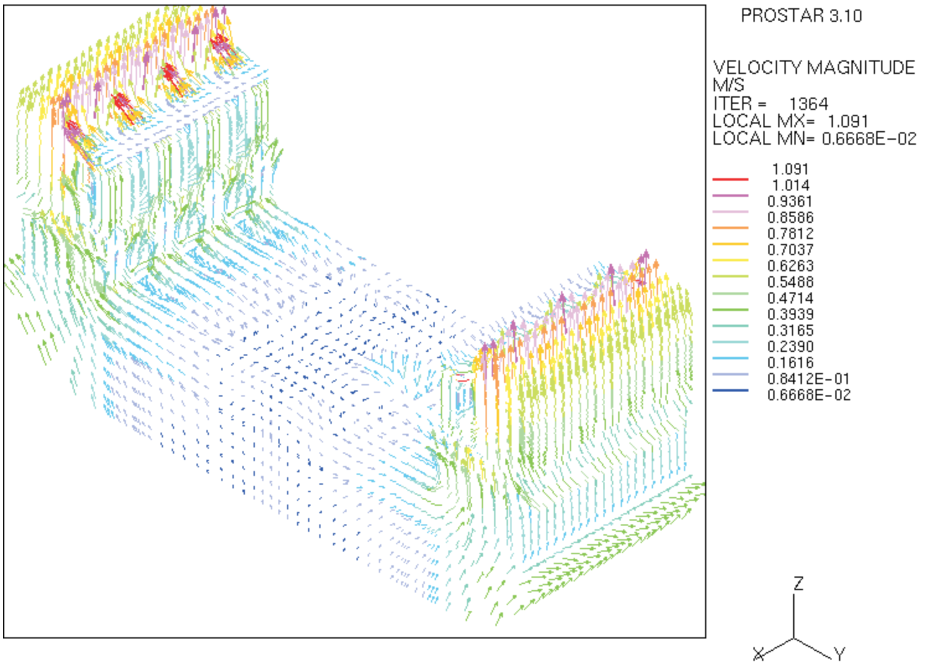
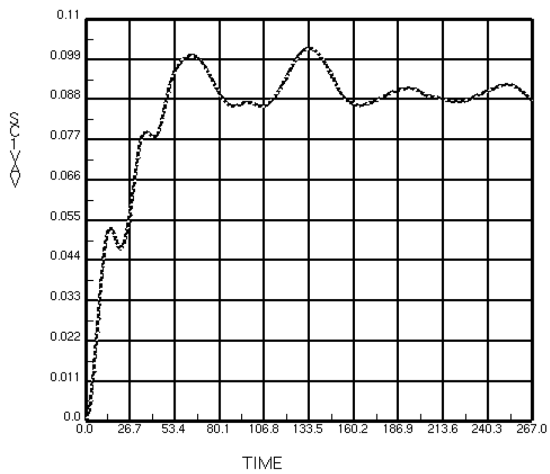


Fig. 2. Free convection velocities. Central part.

The heat transfer due to radiation increases greatly in the housing domains with a high temperature so a thermal radiation model must be applied. The ledge profile is also obtained after solving the conjugate heat transfer problem. A mandatory ventilation problem as an example of the "local" model usage also can be solved using this approach. The side surface of the shell is cooled by a series of jets. To find the temperature decrease on the surface of the housing as a function of jet velocity, the flow around one section can be calculated. The boundary conditions are taken from the solution of the whole problem.

To find the temperature on the surface between the upper and lower parts of the model, the conjugate heat transfer problem is to be solved. The cell produces heat and electrolytic gases that must be taken into consideration when solving that problem as well as natural convection and ventilation in the upper part. As

Fig. 3. The level of disturbances.



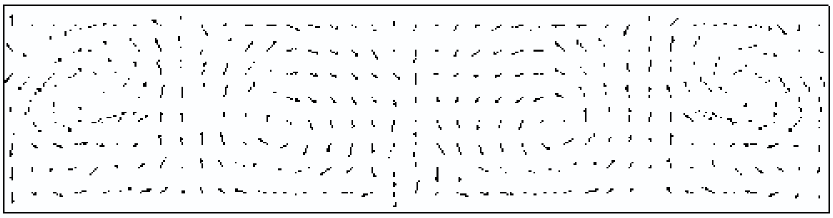


Fig. 4. Circulation zones in the bath.

a result of this solution, the boundary conditions for both parts of the model can be obtained.

BLUMS code is used to calculate the magnetic induction [3]. As an input, it needs the current density distribution. The next problem to be solved is the determination of the metal and bath motion in the reduction cell. The shape of the side ledge found in the heat transfer problem is used as a boundary condition. The Lorentz force, which can be treated as the momentum source for the motion equations, is equal to cross-product of current density and magnetic induction. Magnetic Reynolds numbers are small in this motion so it is assumed that the Braginski approximation is valid [4] and the magnetic induction does not change in spite of disturbances in the current density field. So the magnetic induction is calculated only once before free surface-current iterations begin.

The motion of the system of two liquids is governed by the Navier–Stocks equations with momentum source components corresponding to the external forces in the right sides of the equations. As the Reynolds number of the flow is about 10^5, the flow is considered to be turbulent and the k-model of turbulence is employed to define the Reynolds stresses and turbulent scalar fluxes. The hydrodynamic criteria for disturbance level proposed in [1, 2] can be used in solving the MHD-stability problem (Fig. 3).

The motion induced by the Lorentz force forms several circulation zones. In Fig. 4 the vector field of flow velocity is presented in the horizontal plane section. The temperature distribution obtained in the heat transfer problem can be used to find stresses in solids. Stresses have thermal nature and are calculated using ANSYS code.

5. Conclusions. The system of 3D mathematical models is developed and successfully used for reduction cell analysis. The main model calculations are made on a unified grid using splitting computation of the whole problem into simultaneous computations of separate physical processes. Independent mathematical model (or set of models) and individual processor are used for each physical process. Data transfer is to be organized between these computational processes. At least three problems should be solved in parallel computing: calculation of current density, conjugate heat transfer problem and determination of metal/bath motion including the free surface distortion.

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