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A SIMULATION SYSTEM FOR DIRECT CHILL CASTING OF ALUMINIUM ALLOYS

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ABSTRACT

This paper represents an overview of a simulation system for direct-chill casting of aluminium alloys. The simulation system calculates transient fluid and solid mechanics phenomena in the slabs and billets as a function of the process parameters. Basic characteristics of the system are shown. The system is currently used for optimum setting of the process parameters and calculation of the caster regulation parameters. Verification and validation process of the system are briefly described. Representative examples of the system output are shown.

Keywords: numerical model, temperature, velocity, microsegregation, macro-segregation, optimisation

1. INTRODUCTION

The Slovenes produce about seven times more primary aluminium than the EU average and about three times more aluminium products than the EU average. Consequently, there is a great interest in advanced process and materials development connected with aluminium.

Direct chill (DC) casting [1] is currently the most common semi-continuous casting practice in non-ferrous metallurgy. In this process molten metal is fed through a bottomless water-cooled mould, where a solid shell forms around the outer surface, which is sufficiently thick that the casting takes the shape of the mould and acquires the sufficient mechanical strength to support the molten core in the centre. As the strand emerges from the mould, water flows from the mould and impinges directly on the ingot surface (direct chill), falls over the cast surface and completes the solidification. Many improvements of the process have been made in last years, such as the pressurized air gap between the mould and the ingot, more advanced multi-zone DC cooling, etc. In parallel with the constructional changes, many improvements have been made with use of the informatisation technology in DC casting.

The principal aim of any materials science modelling [2-5] is in the first place the prediction the product properties as a function of the process parameters. This task can be broken down into following three linked subtasks: modelling of the relations between process parameters and macrostructure of the product, modelling the relations between macrostructure and microstructure of the product, and finally, modelling of the relations between microstructure and properties of the product. Despite the massive developments of related theory, experiments and computation, the task of predicting the properties of the product as a function of the process parameters through modelling alone is still a largely unresolved problem. However, some shortcuts leading to reasonable results are possible if modelling is complemented by empirical findings.

In order to improve the direct-chill casting process, the following strategy has been adopted at IMPOL d.d. company: (1) improved insight into the process, (2) improved control of the process, (3) improved understanding of the process, and (4) improved organisation of the work, connected with the process.

(1) Improved insight into the process has been achieved with computer monitoring, acquisition, and storage of the process parameters [6].

(2) Improved control of the process has been achieved with the computerised on-line automatic setting of optimum process parameters.

(3) Improved understanding of the process has been achieved with the computer models of different involved phenomena.

(4) Improved organisation of work around the process has been achieved with the modified working and safety guidelines, and with training of the workers.

2. SIMULATION SYSTEM

The simulation system [7] (Fig. 1) calculates the steady and transient temperature (Fig. 2), velocity (Fig. 3), and concentration (Fig. 4) fields in DC cast billets and slabs. The system is in constant upgrading since the beginning of the nineties. The transport phenomena are calculated within the mixture continuum formulation. For this purpose a set of macroscopic equations is employed [8], which include mass conservation, species conservation for each alloying element, momentum conservation and energy conservation equations. The macroscopic system of equations is closed by a set of microscopic considerations [9] from which the phase quantities are calculated from the mixture quantities. The thermal stress and deformation calculations rely on the assumption of the rate of deformation change due to elastic deformation, viscoplastic deformation, thermal deformation (Fig. 5) and deformation due to phase change [10]. The system can interface with the aluminium alloys material properties database JMatPro [11].

Not all of the listed models are numerically implemented at the present time. Some of the models are employed only for steady state computations without transient capabilities, some of them are for binary alloys only.

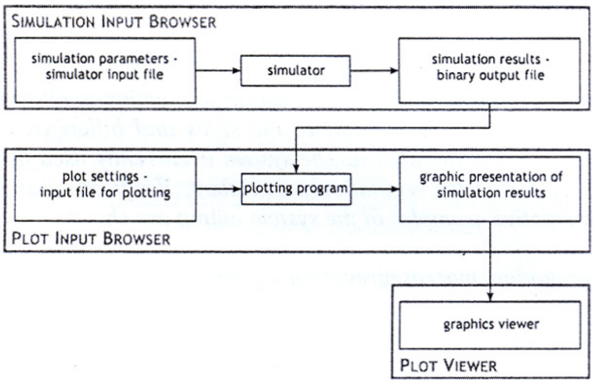

Fig. 1. Schematics of the simulation system

3. VERIFICATION AND VALIDATION OF THE SIMULATION SYSTEM

Parallel to the development of the DC casting models, experimental techniques related to the DC casting process were developed. They were designed and measurements carried out in the IMPOL d.d. company.

The verification of the system represents the answer to the question: Are we solving the equations correctly? For this purpose the governing equations are solved with the classical numerical method, as it is used in the simulation system, and with some alternative numerical method, such as for example the dual reciprocity boundary element method [12] or diffuse approximation method (Fig. 6).

The validation of the systems represents the answer to the question: Are the equations we are solving correct? For this purpose the model results were compared with the results of experiments [13]. The simplest measurement is the product deformation. The measurements of the depth of the liquid sump in case of pure aluminum can be carried out by insertion of a steel rod into the sump. The position of the mushy zone can be measured by flooding of the liquid sump by zinc (Fig. 7) that is much heavier than aluminium and floats out the molten aluminium. The measurements of the steady and transient temperature fields in the DC cast strands can be performed (Fig. 8) by immersion of thermocouples [14].

Because of safety considerations this cannot be done in the vicinity of the strand surface. Because of that, heat flux measurements have been performed on the DC billet surface with a specially designed measurement device (Fig. 9) for measuring the cooling water temperature increase [15]. This data is used for calculation of the heat flux boundary conditions. The concentrations of alloying elements (macrosegregation) in the cast product are measured by the emission spectroscopy.

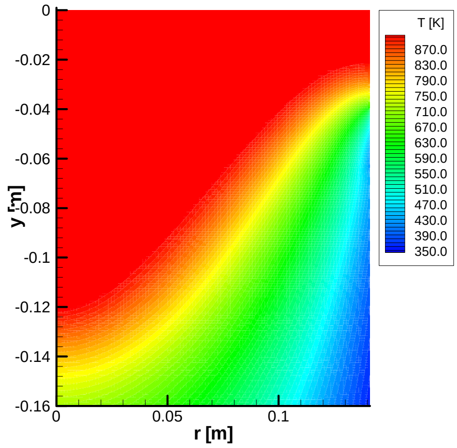

Fig. 2. Calculated temperature field.

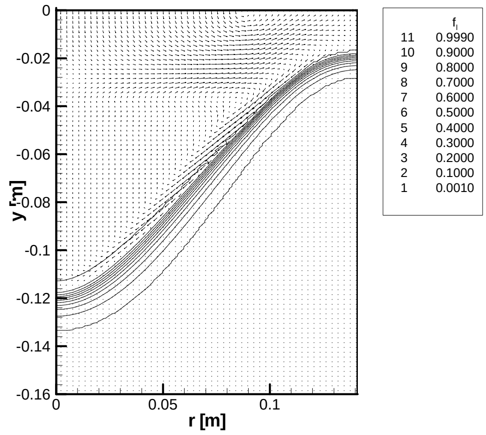

Fig. 3. Calculated velocity field.

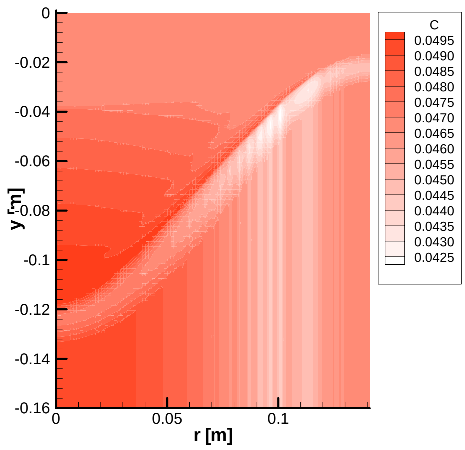

Fig. 4. Calculated macrosegregation field.

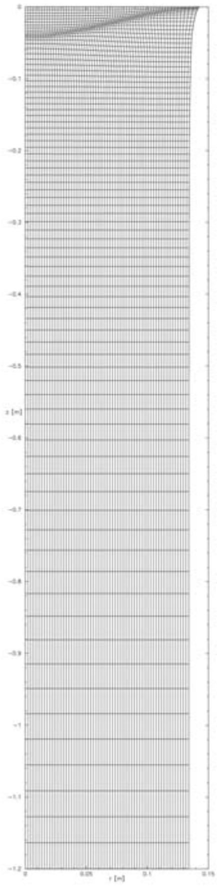

Fig. 5. Calculated thermal deformation field

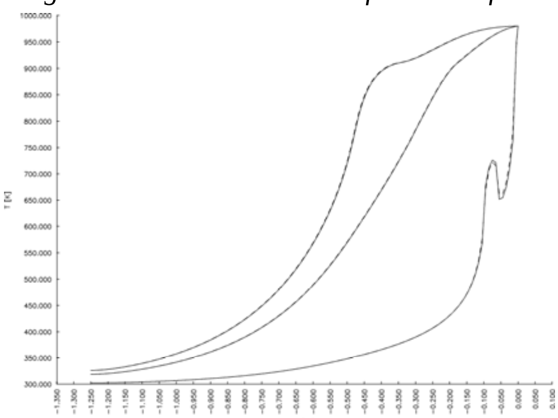

Fig. 6. Model verification. A comparison between FVM and Diffuse approximaion method.

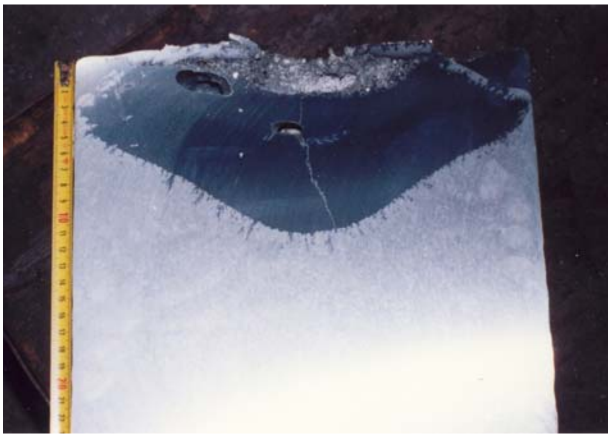

Fig. 7. Zinc flooding measurements.

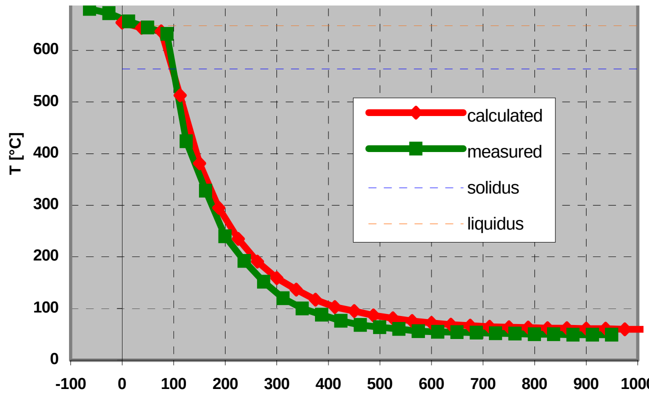

Fig. 8. Model validation. A comparison between measured and calculated billet temperatures.

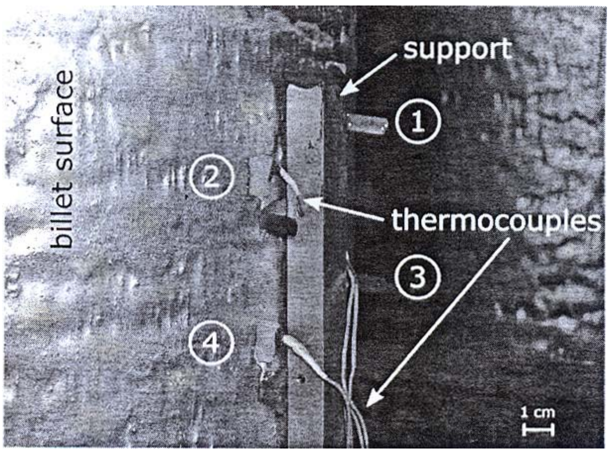

Fig. 9. Thermocouple rack for heat flux measurements

4. USE OF THE SIMULATION SYSTEM

A very recent experimental version of the system is used in the Laboratory for multiphase processes only. The further developed version with user-friendly interfaces and user help (Fig.10) are employed by the Research department and technologists of the IMPOL company. The system is used in the off-line and in the on-line mode. The on-line mode is used primarily for calculation of the process regulation coefficients. The off-line mode is used in estimation of the proper casting conditions and optimization of the casting conditions with respect to the heat fluxes, water temperature increase, position of the melt in the mould/graphite ring, position of the solidus and liquidus at the surface and at the centre of the strand. Current developments are primarily directed into optimization of the product macrosegregation pattern and microstructure.

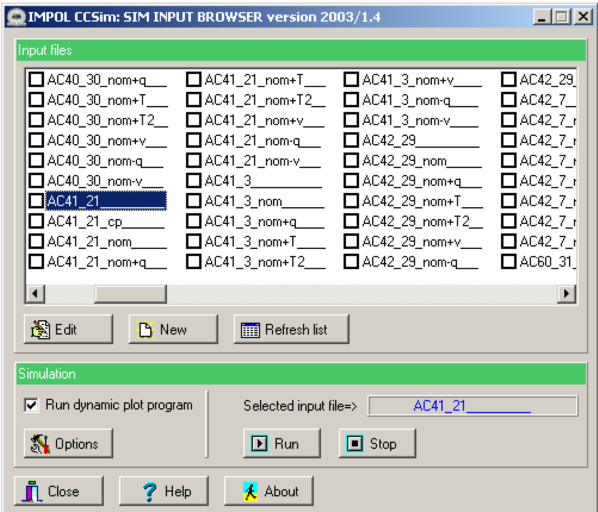

Fig. 10. A typical input-output dialog box.

5. CONCLUSIONS

Computer modelling techniques are now widely used in all scientific disciplines. A particularly fruitful area of application is the field of materials science, where the computational tools are now indispensable for studying and optimisation of the structure, properties and processing of materials. This paper gives an overview of the computational methodologies used in connection with the DC casting process in IMPOL d.d. company in the last decade. The system is successfully used for improvement of the process yield and product quality.

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