NUMERICAL MODELLING OF SOLIDIFICATION OF CONTINUOUSLY CAST STEEL BILLETS OF ROUND FORMAT WITH A DIAMETER OF 130 MM

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Abstract

The paper is devoted to verification of solidification of continuously cast round steel billets with a diameter 130 mm in the ProCAST simulation programme. The aim of numerical modelling realized under the conditions of the Department of Metallurgy and Foundry and Regional Materials Science and Technology Centre (RMSTC) at VSB-TU Ostrava is the optimization of the production of continuously cast steel in ArcelorMittal Ostrava a.s. Primary simulation focused on modelling of the 3D geometry of the thermal steady state of computation and prediction of metallurgical length. Input parameters of computation were determined by the real conditions of the casting. Material properties of the individual components of the casting system were defined by the CompuTherm thermodynamic database, by selection from the database of ProCAST, and finally checked by thermal analysis and calculation of the equations generally used to determine liquidus and solidus temperatures of steel. The thickness of the solidified shell of the strand was predicted. The thickness of the shell is of the essence when assessing the risk of a breakout. Furthermore, the metallurgical length and the two-phase zone were also predicted. In the next phase of the research the attention will be focused on the verification of the heat transfer coefficients and numerical modelling of stresses occurring in continuously cast round steel billets.

Keywords: Steel, CCM, round billets, numerical modelling, metallurgical length

1. INTRODUCTION

Continuous casting technology is currently the primary method in production of steel billets and slabs. In continuous casting, a ladle is placed over a tundish, which feeds one or more moulds beneath through a submerged entry nozzle. The mould area is the zone of primary cooling. Molten steel solidifies and shrinks in the mould, inevitably forming gaps, which is a restrictive condition in continuous casting, between the solidified shell and the mould's copper wall. The mould design should adapt to the heat shrinkage of the billets, therefore a converse taper is recommended to use for the mould inner cavity to reduce the formed gap, increase the thickness of the solidified shell, and to improve the casting speed and the surface quality of the billets [1, 2].

The steel strand is continuously withdrawn from the mould by the guide and pinch rolls. Immediately below the mould, the strand meets a series of water-mist sprays that help extract a significant portion of heat from the moving strand, thereby completely solidifying the steel. We are talking about the zone of secondary cooling.

The primary and secondary cooling must ensure the continuous casting of steel without strand breakouts and other interruptions with an acceptable level of external and internal defects (i.e., surface depressions, cracks, internal porosity, and so on) [2]. But the internal defects also depend on the steel cleanness that is a function of the conditions of refining of steel during secondary steelmaking and casting [e.g. 3, 4, 5, 6].

One of the ways to monitor and optimize the production steps from the casting up to the process of forming of continuously cast steel billets is the use of methods of numerical or physical modelling [e.g. 7, 8, 9, 10, 11]. The aim of numerical modelling realized under the conditions of the Department of Metallurgy and Foundry and Regional Materials Science and Technology Centre (RMSTC) at VSB-TU Ostrava is the optimization of the production of continuously cast steel billets of round format with a diameter of 130 mm in ArcelorMittal Ostrava a.s., especially focused on minimization of centreline porosity and surface cracks. Surface cracks are initiated in the mould region of the caster. They subsequently develop in the secondary cooling zone or even later, such as during reheating. Cracks are formed because of mechanical and thermal stresses, and material factors [12]. Based on available literature [e.g. 13], it was confirmed that the quality of continuously cast steel billets is also a function of chemical composition of the steel, of the time and course of solidification. This means that in order to minimize the extent of defects it is necessary to optimize the regime of the casting and the control of solidification, as was mentioned e.g. in the literature [14].

In the first stage of an extensive modelling research under so-called steady state thermal conditions, the attention of numerical modelling was focused on the definition of 3D geometry of the round billets, on the identification of boundary conditions and materials properties. Based on the primary results, the thickness of the solidified shell of the strand, the metallurgical length and the two-phase zone were predicted.

2. DEFINITION OF NUMERICAL MODEL

Generally, the numerical solution of each task is divided into three stages: 1. Pre-processing: includes the geometry modelling and the computational grid generation process, and definition of calculation. 2. Processing: involves the computation in the solver. 3. Post-processing: focuses on evaluation of the results. In order for the default version of the numerical model of the solidification of the steel billets aimed to predict the extent of the defects to correspond to real solidification conditions as accurately as possible, it was important to define the parameters of the calculation correctly. Determination of some boundary, operating and initial conditions is usually not relatively difficult. The casting speed or the casting temperature of the steel was defined according to real casting conditions used in ArcelorMittal Ostrava a.s. The quality of the results of the numerical simulation of the volume defects in continuously cast billets is mainly determined by the quality of the thermodynamic properties of steel and of mould material, respectively by the applied conditions of heat transfer among the individual parts of the casting system and by the definition method of the heat losses along the casting strand. And here is where the first difficulties can be encountered. First, if the grade of the steel may not be included in the basic material database of the ProCAST software, the integrated CompuTherm thermodynamic database can be used to solve this issue. Based on the definition of chemical composition of the steel, the thermodynamic database CompuTherm, allows the user to calculate thermodynamic parameters for any new material, or to follow the changes of the thermo-physical data relating to changes of chemical composition [15]. Another way is to use the experimental method of thermal analysis [16, 17], or it is also possible to use information from literature. Also, the definition of the heat transfer coefficients among the individual components of the casting system is not simple.

2.1 Geometry modelling and computational mesh generation

Mirror symmetry was used in the preparation of the mould and strand geometry. Computation was carried out on half of entire geometry (**Fig. 1**). The reason for the use of one symmetrical half of the geometry is shorter computation time at a much finer mesh-work.

The geometry created includes the entire curved section and also the 3 m straight section of the strand. In order to simulate the metallurgical length geometry must be drawn only up to the end of the tertiary cooling zone. So according to rough calculation, another approximately 3 m straight section of the strand must be then added to the curve.

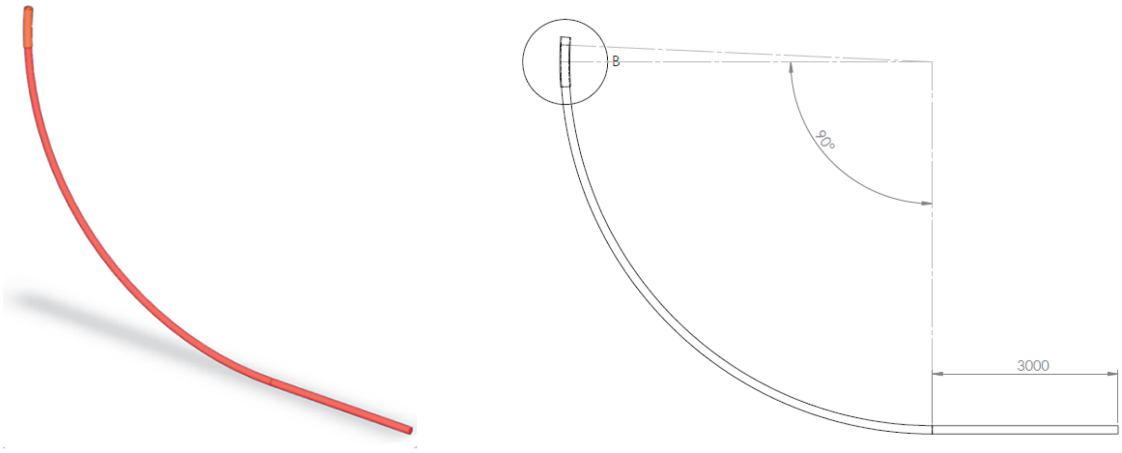

Fig. 1 Geometry of the round format CCM with a diameter of 130 mm specified for the computation

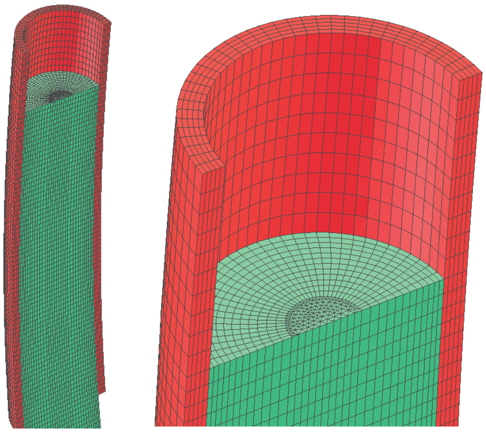

Fig. 2 Detailed view of the computational mesh in the mould and strand area

The level of steel in the mould was marked from its upper edge. The nozzle is not considered in the heat calculation. Secondary cooling and the rolls are replaced with the thermal boundary condition. There is only one part of the mould unit considered in the calculations. It is a curved copper tube, which is on its inner side in contact with the strand, and on its outer side cooled by water flowing in a closed circuit. Water-cooling is replaced by a heat flux boundary condition.

The structured volume mesh containing a hexa and a wedge element was prepared (**Fig. 2**). Density of the mesh was designed with regard to thermal gradients in the mould and the strand.

2.2 Material properties

Definition of computation parameters consisted in the identification of thermodynamic properties of cast steel. To determine these properties the thermodynamic database CompuTherm, which is integrated in the ProCAST software was used. Theoretically obtained data (the solidus and liquidus temperature, heat capacity) were also verified using thermal analysis.

2.3 Interface

The interface corresponded to interface heat transfer coefficients (HTC) between two different domains, where the “coincident” or “non-coincident” interface has been defined. In an interface between two different materials, such as the ingot and the mould, there is usually a temperature drop. In this case, the nodes at the interface should be doubled (for a coincident interface) in order to distinguish temperature on each side of the interface.

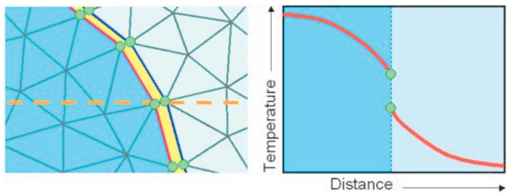

Fig.3 Illustration of the coincident interface between two different domains [15]

Since there has been one node in the interface during grid generation, it is necessary at this stage to duplicate all the interface nodes (as shown in green in **Fig. 3**). This duplication operation is performed when "COIN" is selected. The interface, which is highlighted in yellow in the **Fig. 3** has in fact a zero thickness [15]. In our case, the coincident condition was used between the interface of the billets and mould.

2.4 Boundary conditions

The casting temperature of steel was set to meet technological conditions used in ArcelorMittal Ostrava a.s. Furthermore, it was necessary to define the heat transfer for the side surfaces of the mould, for the casting faces, for the top, bottom, and the bottom surfaces of mould. The method of heat transfer across the billet surface was described with the user function. Heat transfer coefficients (HTC) were set according to the experience of investigators and the data available in the literature. Heat transfer from the mould was described using the Water-cooling and Air-cooling function listed in the basic menu of Boundary Conditions of the PreCAST module.

3. ACHIEVED RESULTS

The simulation results show the so-called steady thermal state of continuous casting. As for the balanced temperature computation of the first version of the model, our attention was focused on the end result of solidification. **Fig. 4** shows a temperature field on the surface of the strand. During the evaluation of results the main attention was paid to the assessment of thickness of the solidified shell at the end part of the mould, the metallurgical length and the two-phase zone. Thickness of the solidified shell, particularly its uniformity is essential, for example in terms of formation of the surface depressions, cracks and the risks of breakout. Thickness of the solidified shell at the end of the mould was 10.4 mm (**Fig. 5**). The metallurgical length with the given computation parameters was 11.31 m, and the two-phase zone length equalled to 2.21 m (**Fig. 6**).

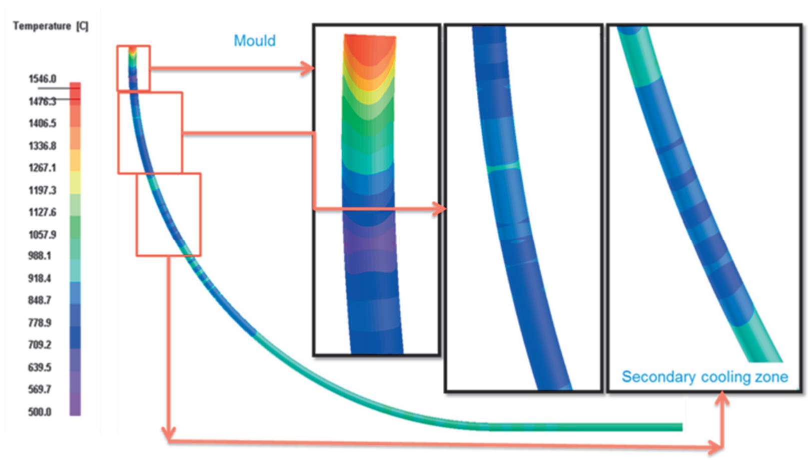

Fig. 4 Temperature field on the surface of the strand

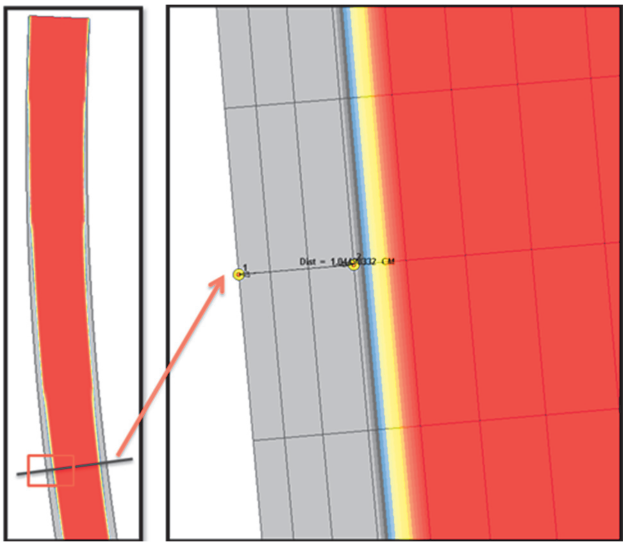

Fig. 5 Thickness of solidified shell at the end of the mould, which was 10.4 mm

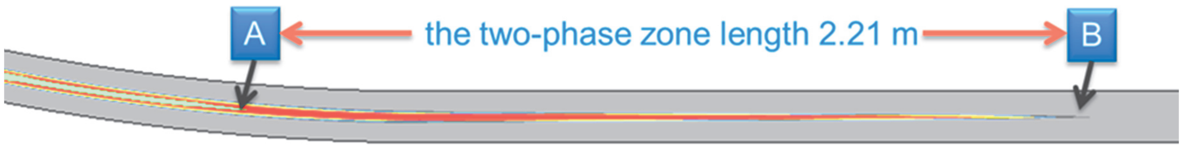

Fig. 6 View of the length of the two-phase zone

CONCLUSION

The geometry followed by the computational mesh for the numerical simulation of solidification of continuously cast steel billet of a round format with a diameter of 130 mm was prepared. The simulation results show the so-called steady thermal state of continuous casting. The thickness of a strand's solidified shell at the point where it leaves the mould was predicted. Furthermore, the metallurgical length as well as the two-phase zone was predicted as other important variables for analysis of the right setting of a continuous casting machine.

The next stage of the research will focus on verification of heat transfer coefficients and implementation of experimental liquidus and solidus temperatures of cast steel grades, determined by thermal analysis. The results of experimental studies will be then applied to refine the setting of a numerical model of solidification of the billet. Numerical computation of solidification, including prediction of stress states, will be also carried out in the following stage.

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