INVESTIGATION OF TECHNOLOGY OF CONTINUOUSLY CAST STEEL BILLETS USING NUMERICAL MODELLING

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Abstract

The paper is devoted to verification of solidification of continuously cast round steel billets with a diameter 400 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. The temperature field, the thickness of the solidified shell, the metallurgical length and the porosity were predicted under different boundary conditions of continuous casting. To achieve mentioned results, the same type of the geometry, a computational mesh and also a definition of the numerical model were used. The paper describes the pre-processing, processing and post-processing phases of numerical modelling. The advantages and disadvantages of mentioned methods are discussed and possible future developments are outlined.

Keywords: Steel, continuous casting, numerical modelling, metallurgical length, porosity

1. INTRODUCTION

Continuous casting (CC) technology is currently the main method used to produce the steel billets, blooms or slabs. Molten steel is during CC solidified into „semi-finished" products for subsequent rolling in the finishing mills. Enhancement of the number of heats cast in a sequence, if possible without interruption of casting and without necessary restart, is of utmost significance for increasing the productivity of continuous cast steel. On the other hand, CC of various steel grades requires individual processing parameters. Therefore, a fundamental task of the CC method is the optimization of the processing parameters in order to maximize the safety of the process, to improve the economy and ecology of the technology and mainly to increase the quality of the products [1].

One of the ways how to monitor and optimize the processing parameters of the CC technology, respectively the temperature profile of the cast strand and the quality of the semi-finished products, is the application of numerical modelling [2], in which numerical methods are used for solving mathematical equations of the mass transfer, movement and energy.

In this study, numerical modelling using the finite element method has been developed for verification of the temperature field, the thickness of the shell at the end of the mould, the metallurgical length and the porosity for continuous casting of the round steel billets with a diameter of 400 mm.

2. MODEL DESCRIPTION

Generally, numerical solution of each task is divided into three stages: 1. Pre-processing: it includes geometry modelling and the process of generation of the computational mesh, and definition of calculation. 2. Processing: it involves computation in the solver. 3. Post-processing: it focuses on evaluation of the results.

2.1. Geometry and FEM mesh

Computation was carried out on half of the entire geometry (**Figure 1**). The created geometry includes the entire curved section and also the straight section of the strand.

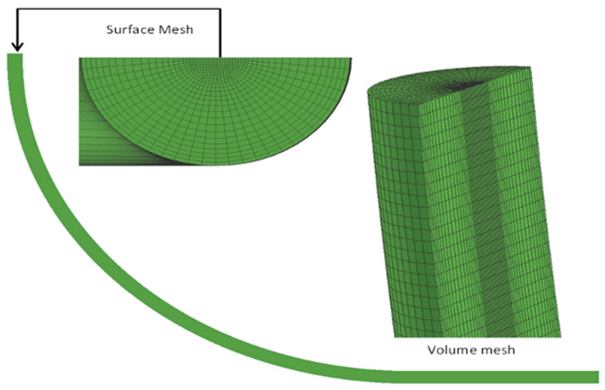

Figure 1 Geometry and the detailed view of the computational mesh

In order to simulate the metallurgical length, the geometry must be drawn only up to the end of the tertiary cooling zone. The level of steel in the mould was marked from its upper edge. The nozzle was not considered in the heat calculation. As the main algorithms of the technic of calculation was used the Traveling Boundary Conditions, therefore the secondary cooling and the rolls were replaced with the User Function of thermal boundary condition. The structured volume mesh containing a hexagonal and a wedge element was prepared (detail in **Figure 1**). Density of the mesh was designed with regard to thermal gradients in the mould and in the strand.

2.2. Thermo-physical parameters

Continuous casting process of steel 34CrMo4 containing approx. 0.35 wt. % C was simulated. Due to the fact that the simulated steel grade was not included in the basic material database of the simulation programme, the integrated thermodynamic database was used to calculate the thermodynamic properties. For determination of liquidus and solidus temperature and heat capacity, the thermal analysis can be also used [3]. The liquidus temperature of the steel was 1499 °C, and the solidus temperature was 1455 °C. **Figure 2** shows the calculated thermo-dynamic properties of steel, such as density and enthalpy.

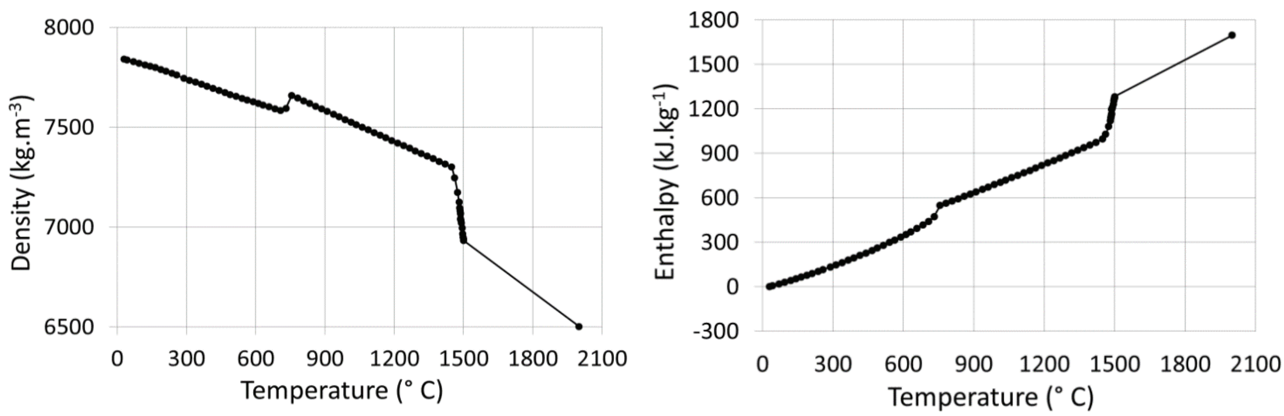

Figure 2 Calculated thermo-dynamic properties of the studied steel

2.3. Boundary conditions, operating conditions

The boundary conditions, such as casting speed and casting temperature, were defined according to the plant data. The ambient temperature was 25 °C. The level of the steel in the mould was 80 % from the height of the mould. The gravitational acceleration was 9.82 $m \cdot s^{-2}$. The standard pressure was considered to be 101325 Pa.

2.4. Mathematical formulation of thermal processes and determination of heat parameters

From the physical point of view, the numerical modelling of continuous casting represents the heat and mass transfer under non-stationary conditions where the heat conduction is mainly applied. The other mechanisms of the heat transfer, such as the radiation and convection, play a role mainly at definition of boundary conditions of the process in the secondary and tertiary zone of the CC machine.

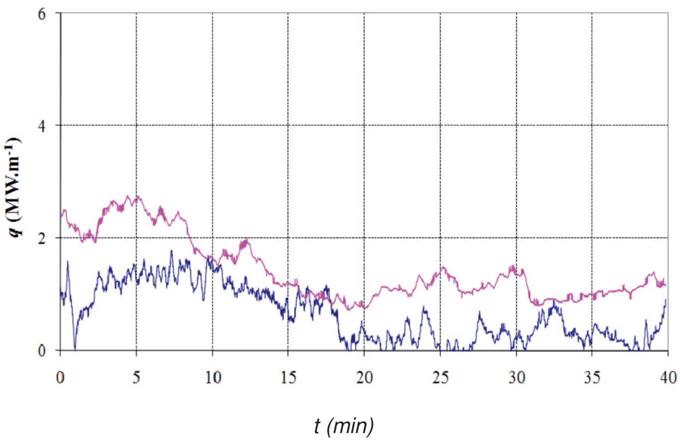

Figure 3 The example of the profile of heat flux along the mould with diameter of 410 mm cited from lit. source [6]

Also, the phase changes, which may occur during solidification of the steel, must be included in the numerical formulation. To describe the heat transfer during continuous casting, the Fourier-Kirchhoff equation can be used [4]. In the case of radial CC machine, it is good to transform the cylindrical coordinates into the Fourier-Kirchhoff equation.

The mould area is the zone of the primary cooling [5]. The gaps between the solidified shell and the mould copper wall present a restrictive condition at continuous casting. **Figure 3** shows the profile of the density of heat flux from the surface of the steel into the mould for the round billets with diameter of 410 mm [6].

In the presented study, the water cooling in the mould region was described by a user function of a heat flux boundary condition. The user function took also into account the formation of the gas gap between the mould and the steel billets. The user function was used also for definition of the heat transfer coefficients along the casting strand in the secondary cooling zone. Between the individual spray surfaces, the heat loss by conduction and radiation was considered. The user functions were defined in the programming language C++ as the Traveling Boundary Conditions. To be sure of the values of the heat transfer coefficients used in the function, the temperatures on the surface of the cast strand were measured under real casting conditions.

3. RESULTS AND DISCUSSION

In the first stage of extensive model study, the attention was concentrated on the modelling of three technological cases of continuously cast round billets with a diameter 400 mm for one chosen type of steel grade. The simulated variants differed according to the casting speed and casting temperature. Also, the cooling in the primary and secondary zone had to be adapted individually for each technological case. Overview of simulated variants is given in **Table 1**.

Table 1 Overview of simulated variants

Variant No.	Name of Variant	Casting Speed, ($m \cdot min^{-1}$)	Casting Temperature, (°C)
1	Z-01,t+16	v - 0.1	t + 16
2	Z0,t	v	t
3	Z+01,t-12	v + 0.1	t - 12

From the **Table 1** can be seen, that the basic technological case represents the variant No. 2. The second technological case which can be occurring under real casting condition is the variant No. 1. The variant No. 1 represents the case when the casting speed is lower about 0.1 $m \cdot min^{-1}$ and the casting temperature at the tundish is higher about 16 °C comparing with the basic variant No. 2. On the other hand, the variant No. 3 is that technological case when the casting speed is higher about 0.1 m·min^{-1} and the casting temperature at the tundish is lower about 12 °C comparing with the basic technological variant No. 2.

3.1. Surface temperatures, metallurgical lengths, thickness of the solidified shell

Figure 4 shows a temperature fields on the surface of the strand for the three simulated cases. The obtained profiles of the temperature changes were compared with the information from the real plant measurement of temperatures on the surface of the cast strand using the pyrometers.

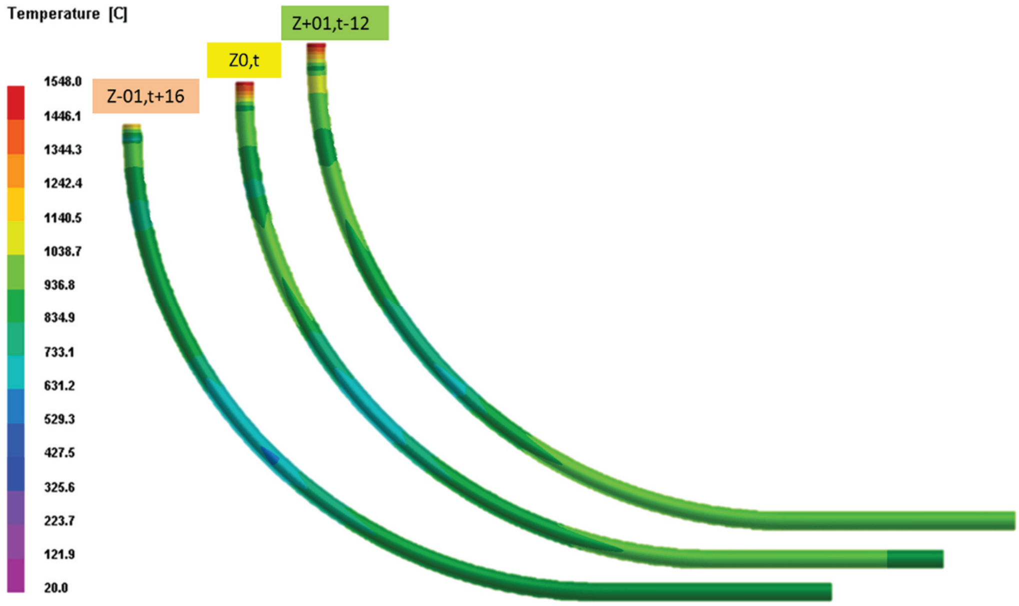

Figure 4 Comparison of the temperature fields on the surface of the strand for the three simulated cases

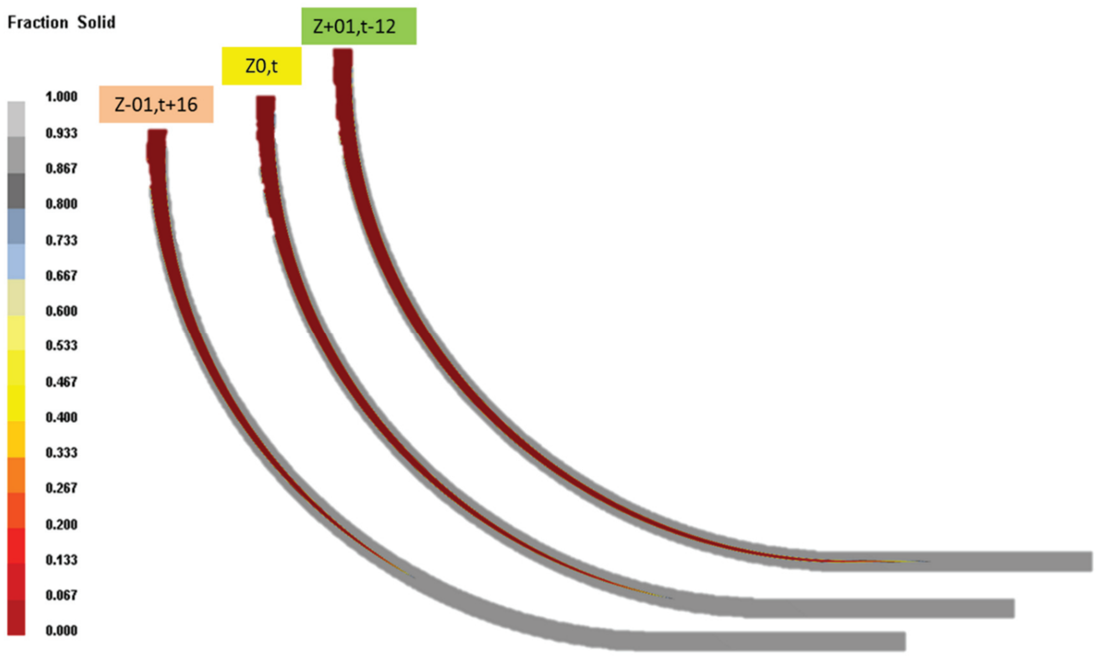

Figure 5 Comparison of the metallurgical lengths of the three technological cases using Fraction Solid

During evaluation of results, the main attention was paid to the assessment of thickness of the solidified shell at the end part of the mould, and of the metallurgical length. **Figure 5** shows the results of Fraction Solid from which can be measured the thickness of the shell at the end of the mould and also a final character of the metallurgical lengths. The knowledge of the thickness of the solidified shell, particularly its uniformity, is necessary from the reason of formation of the surface depressions, cracks and from the reason of the risk of breakout. The thickness of the solidified shell at the end of the mould was 22 mm for variant Z0,t. In the case of variant Z+01,t-12 was 18 mm and in the case of variant Z-01,t+16 was 26 mm. The metallurgical length with the given computational parameters was 15 m for variant Z0,t; 18.5 m for variant Z+01,t-12 and the 12 m for variant Z-01,t+16. From the results it can be seen, that the metallurgical length grows with the increasing casting speed. On the other hand, the thickness of the shell at the end of the mould was decreasing.

3.2. Risk of the Porosity

The porosity was predicted using the Advanced Porosity Module. Because the microporosity was not found out based on the actually setting of the numerical model, the liquid pressure was used for the evaluation of the evolution of the porosity depending on the boundary conditions of the casting. The value zero of the pressure signalizes the origination of the porosity. The comparison of the liquid pressures of simulated variants is shown in **Figure 6**. It can be seen, that the porosity should not be created under actual real casting conditions. These results were confirmed by metallographic analyses of the real steel samples.

Figure 6 Comparison of the liquid pressure (Pa) in the cross section of the part of the continuously cast steel billets of round format with diameter 400 mm

4. CONCLUSION

The aim of numerical modelling using the finite element method was to verify the temperature field, the thickness of the shell at the end of the mould, the metallurgical length and the final porosity in continuously cast round steel billets with a diameter of 400 mm. Using the numerical modelling, it was found that:

- the geometry for simulation of the solidification of the continuously cast billets depends on the type of required results; for prediction of the metallurgical length it is possible to use the entire geometry of the casting strand, but it is useful to apply the condition of symmetry in order to achieve a shorter calculation time;
- the advantage of the numerical modelling considering metallurgical conditions of the steel production is the possibility of relatively simple change of the boundary conditions of the CC technology and

verification of the influence of these processing parameters changes on the final character of solidification of the casting strand, respectively on the final temperature profile and on the size of the final defects;

- nevertheless, a prerequisite for correct results of numerical modelling is the relevant description of the thermodynamic properties of the steel and of the heat transfer in the steel continuous casting process. Such description is very difficult, because the cooling and solidification processes of continuously cast products are influenced by many factors, such as casting format, casting speed, casting temperature/ superheating, steel grade/ carbon content, erosion of the mould, electromagnetic stirring, efficiency of the cooling in the secondary zone etc.

The next stage of the research will be focused on the validation of the porosity and of the risk of the cracks under different boundary conditions of the casting and the character of the temperature field with flow calculation will be also evaluated.

ACKNOWLEDGEMENTS

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