THE EFFECT OF CASTING SPEED AND CHEMICAL COMPOSITION ON THE RESULTANT TEMPERATURE FIELD OF A SLAB

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Abstract
The analysis of the effect of the casting speed and chemical composition on the resultant temperature field of a slab was conducted using an original off-line model of its temperature field. For this analysis it was necessary to select the output quantities that could be exactly defined and compared, or to choose a specific course/history of the compared output parameter that could be exactly defined. The most favourable one seemed to be the maximum metallurgical length (i.e. the apex of the solidification cone), the maximum distance from the mould where melt still occurs, the temperature of the surface of the slab in the area of the bend and the surface temperature of the slab in the point where the slab exits the cage of the secondary-cooling zone.

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1. A MODEL OF THE TEMPERATURE FIELD OF A SLAB

The 3D model had first been designed as an off-line version and later as an on-line version so that it could work in real time \cite{1}. After correction and testing, it will be possible to implement it on any caster thanks to the universal nature of the code. The numerical model takes into account the temperature field of the entire slab (from the meniscus of the level of the melt in the mould to the cutting torch) using a 3D mesh containing more than a million nodal points.

The solidification and cooling of a concast slab is a global problem of 3D transient heat and mass transfer. If heat conduction within the heat transfer in this system is decisive, the process is described by the Fourier-Kirchhoff equation. It describes the temperature field of the solidifying slab in all three of its states: at the temperatures above the liquidus (i.e. the melt), within the interval between the liquidus and solidus (i.e. in the mushy zone) and at the temperatures below the solidus (i.e. the solid state). In order to solve these it is convenient to use the explicit numerical method of finite differences. Numerical simulation of the release of latent heats of phase or structural changes is carried out by introducing the enthalpy function dependent on temperature $T$, preferably in the form of enthalpy related to unit volume $H$. The latent heats are contained here. After the automated generation of the mesh (pre-processing) ties on the entry of the thermophysical material properties of the investigated system, including their dependence on temperature – in the form of tables or using polynomials. They
are namely the heat conductivity $\lambda$, the specific heat capacity $c$ and density $\rho$ of the cast metal.

2. A PARAMETRIC STUDY OF SLAB CASTING

The original off-line model of the temperature field and its calculation speed makes it possible to perform so-called parametric studies, i.e. the analysis of the effect of individual input technological parameters and properties on the resultant temperature field. The results of these parametric studies could serve for the verification of the empirical relationships used, for establishing technological procedures for the caster operators, for the carrying out of comprehensive optimization and for the setting up of the dynamic model. Regarding the fact that the result of the modelling process is a 3D temperature field, it is necessary to select such output parameters that can be uniquely defined and compared or to select the graphics output of the compared output parameter, in order to assess the effect of the chemical composition. The most suitable for the comparison seems to be the maximum metallurgical length, the maximum length of the liquid phase, the surface temperature at the unbending point and the surface temperature the point just before leaving the caster cage. The courses of the temperatures of the same points of the cross-section were selected as the basic graphical representation for comparison along the entire length of the caster, in combination with the graph showing the increase in the thickness of the shell.

There are three types of graphs drawn in order to illustrate the results as clearly and as completely as possible. Figure 2 shows the temperature history of six points of the cross-section of the slab (i.e. in the centre of the slab, in its corners and in the middle of the sides of the surface) in the way that the cross-section passes through the caster (from the meniscus of the steel in the mould all the way down to the cutting torch). The distance from the meniscus inside the mould is plotted on the horizontal axis. The width of the horizontal yellow strip illustrates the temperature interval for the relevant class of steel. The width of the vertical yellow strip illustrates the distance between the isoliquidus and isosolidus (i.e. the width of the mushy zone) in its maximum values. Furthermore, the graph indicates two surface temperatures where the pyrometers were positioned. The red vertical dashed lines are the boundaries between individual segments and, the blue vertical lines represent the meniscus of the steel inside the mould, the bottom edge of the mould, the unbending point and the end of the caster cage. The next graph illustrates the temperature field in the diagram of the caster, where the shades of blue represent solidified steel, the shades of yellow represent liquid steel and the red represents the mushy zone. The last graph is the course of the isoliquidus and isosolidus unrolled along the longitudinal section through the entire concasting. This picture gives a clear idea of the shape of the mushy zone, which closely corresponds to the structure and any potential internal defects.

2.1 A STUDY ON THE EFFECT OF THE CHEMICAL COMPOSITION ON THE RESULTANT TEMPERATURE FIELD

A real concasting operation casts up to several hundred classes of steel. It would therefore be difficult to set the concasting and other relevant technological parameters for all of them. That is why steels are subdivided into groups, mostly according to their carbon content, preferably according to the so-called equivalent carbon content, given by:

\[
E_{eq} = \text{wtC} - 0,1 \cdot \text{wtSi} + 0,04 \cdot \text{wtMn} - 0,04 \cdot \text{wtCr} + 0,1 \cdot \text{wtNi} - 0,1 \cdot \text{wtN}a
\]

For an example it was selected 11325 class steel. Fig. 1 illustrates the dependence of the thermophysical properties on the temperature for this steel. Fig. 2 presents the calculated temperature field for this class of steel.
The calculation of the temperature field of the slab were performed also for other steels [2]. In order to analyse the influence of the chemical composition on the temperature field more clearly, the other concasting parameters were used identical, i.e. the casting speed 0.8 m/min, the superheating temperature 30 °C and the profile of the slab 1530×250 mm, just like the flow of water through the secondary-cooling zone. In practice, a different cooling mode is selected for each different class of steel.

![Graph of Thermophysical properties of the 11325 class steel](image-url)

**Fig. 1.** Thermophysical properties of the 11325 class steel
Fig. 2. Temperature field of the 11325 class steel slab
Figures 3 and 4 prove that the effect of the chemical composition on the resultant temperature field evaluated by the above-mentioned output parameters is significant.

**Fig. 3.** Comparison of the length of the liquid phase and the metallurgical length for various classes of steel

**Fig. 4.** The effect of the chemical composition on the resultant parameters
2.2. THE EFFECT OF THE CASTING SPEED

The casting speed is a basic technological parameter. In calculations, whose results are represented here (for the 11325 class steel), the operating range of the speed is considered 0.7 to 0.85 m/min. The flow of water through the secondary-cooling zone, according to the technological regulations, increases linearly. The other input parameters are again left constant, i.e. especially the superheating temperature of 30 °C. A higher speed need not be investigated because the metallurgical length exceeds the length of the cage, which is unacceptable. On the other hand, lower casting speeds are used only short-term, e.g. in the case that there is the risk of breakout or when the tundish is being exchanged.

The graphs in Fig. 5 and 6 and Table 1 show that there is a linear dependence of all of the monitored parameters (the metallurgical length, the length of the liquid phase, the temperature of the unbending part and the temperature at the end of the cage) on the casting speed. A slight deviation can be seen for lower speeds, which corresponds with the setting of secondary cooling. A casting speed of 0.82 m/min seems to be the optimum for all of these parameters.

Table 1.
Effect of casting speed

<table>
<thead>
<tr>
<th>Class</th>
<th>Casting speed</th>
<th>L_{LIQ}</th>
<th>L_{MET}</th>
<th>T_{unbending}</th>
<th>T_{end}</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m/min</td>
<td>M</td>
<td>m</td>
<td>°C</td>
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<tr>
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Fig. 5. Comparison of the temperature fields for various casting speeds, 11325 class steel, superheating 30 °C
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3. CONCLUSION

In order to analyse the effect of five selected classes of steel on the temperature field, the other input parameters (i.e. the casting speed, the superheating temperature, the slab dimensions and the flow of water inside the secondary-cooling zone) were considered identical. The effect of the chemical composition on the length of the liquid and solid phase proved to be significant. The effect of the casting speed on the temperature field was monitored for class 11325 steel within the range from 0.7 to 0.85 m/min, when the water flow through the secondary-cooling zone – according to technological procedures – was directly proportional to the casting speed.

The other input parameters were again left constant, incl. the superheating temperature. It was not necessary to investigate higher speeds because the metallurgical length exceeded the length of the cage. The graphs indicated that all monitored output quantities were directly
proportional to the casting speed. A slight deviation from this relationship occurred with lower speeds. The results stated that the optimal casting speed was 0.82 m/min.

All these so-called parametric studies were also used to monitor the effect of the superheating of steel and the influence of the dimensions of the slab (which however is not discussed in the paper). They can serve for verification of the empirical relationships, for compiling technological procedures for caster operators, for carrying out comprehensive optimization and for setting the dynamic model.

4. LITERATURE