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THE INFLUENCE OF CHEMICAL COMPOSITION OF STEELS ON THE NUMERICAL SIMULATION OF A CONTINUESLY CAST OF BILLET

VLIV CHEMICKÉHO SLOŽENÍ OCELI NA NUMERICKOU SIMULACI PLYNULÉHO ODLÉVÁNÍ SOCHORŮ

Abstract

The chemical composition of steels has significant influence on the actual concasting process, and on the accuracy of its numerical simulation and optimization. The chemical composition of steel affects the thermophysical properties (heat conductivity, specific heat capacity and density in the solid and liquid states) often requires more time than the actual numerical calculation of the temperature fields of a continuously cast steel billet. Therefore, an analysis study of these thermophysical properties was conducted. The order of importance within the actual process and the accuracy of simulation were also determined. The order of significance of the chemical composition on thermophysical properties was determined with respect to the metallurgical length. The analysis was performed by means of a so-called calculation experiment, i.e. by means of the original numerical concasting model developed by the authors of this paper. It is convenient to conduct such an analysis in order to facilitate the simulation of each individual case of concasting, thus enhancing the process of optimization.

Abstrakt

Chemické složení ocelí má významný vliv na reálný proces plynulého odlévání a na přesnost jeho numerické simulace a optimalizace. Chemické složení oceli ovlivňuje termofyzikální vlastnosti (tepelné vodivosti, měrné tepelné kapacity a hustoty v tuhém i tekutém stavu) a jejich prostřednictvím ovlivňuje výpočet teplotního pole plynule odlévaných ocelových sochorů. Proto byla provedena analýza studie těchto termofyzikálních vlastností. Vliv významu chemického složení na termofyzikální vlastnosti byla určena s ohledem na metalurgickou délku. Analýza byla provedena pomocí takzvaných výpočetních experimentů, tj. pomocí originálního numerického modelu teplotního pole, který byl vyvinut autory tohoto příspěvku. Tato analýza usnadní a tím zlepší proces optimalizace plynulého odlévání oceli.

1 INTRODUCTION

The chemical composition of steels has significant influence on the actual concasting process, and on the accuracy of its numerical simulation and optimization. The chemical composition of steel affects the thermophysical properties (heat conductivity, specific heat capacity and density in the solid and liquid states) often requires more time than the actual numerical calculation of the temperature fields of a continuously cast steel billet. Therefore, an analysis study of these

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thermophysical properties was conducted. The order of importance within the actual process and the accuracy of simulation were also determined. The order of significance of the chemical composition on thermophysical properties was determined with respect to the metallurgical length. The analysis was performed by means of a so-called calculation experiment, i.e. by means of the original numerical concasting model developed by the authors of this paper. It is convenient to conduct such an analysis in order to facilitate the simulation of each individual case of concasting, thus enhancing the process of optimization.

2 A NUMERICAL MODEL OF THE TEMPERATURE FIELD OF A CONCAST BILLET

The presented in-house model of the transient temperature field of the blank from a billet caster (Fig. 1) is unique in that, in addition to being entirely 3D, it can work in real time. It is possible to adapt its universal code and implement it on any billet caster. The numerical model covers the temperature field of the complete length of the blank with up to one million nodes. The solidification and cooling of a blank and the simultaneous heating of the mould is a case of 3D transient heat and mass transfer in a system comprising the blank-mould-ambient and, after leaving the mould, it is a system comprising only the blank-ambient. The solidification and cooling of the blank is described by the Fourier-Kirchhoff equation (1), which contains the components describing the heat flow from the melt flowing with a velocity v_z and the component including the internal source of latent heats of phase or structural changes.

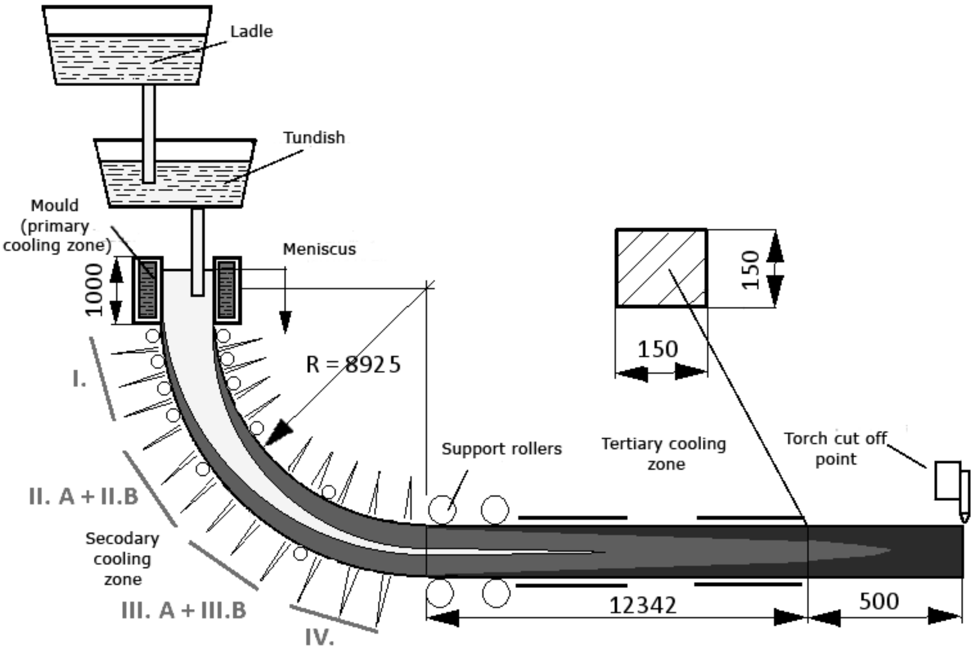


Fig. 1 A billet caster

$$\rho \cdot c \frac{\partial T}{\partial \tau} = \frac{\partial}{\partial x}\left(k \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k \frac{\partial T}{\partial z}\right) + \rho \cdot c\left(v_x \frac{\partial T}{\partial x} + v_y \frac{\partial T}{\partial y} + v_z \frac{\partial T}{\partial z}\right) + \dot{Q}_{source} \tag{1}$$

The temperature field of the blank passing through a radial caster of a large radius can be simplified by the Fourier-Kirchhoff equation where only the v_z component of the velocity is considered. Equtation (1) must cover the temperature field of the blank in all three stages: above the liquidus temperature (i.e. the melt), in the interval between the liquidus and solidus temperatures (i.e. the so-called mushy zone) and beneath the solidus temperature (i.e. the solid phase). It is therefore convenient to introduce the thermodynamic function of specific volume enthalpy $H_v = c.\rho.T$, which is dependent on temperature, and also includes the phase and structural heats. Heat conductivity k, specific heat capacity c and density ρ are thermophysical properties that are also functions of chemical composition and temperature [2].

All thermodynamic properties of the cast steel, dependent on its chemical composition and cooling rate, enter the calculation as functions of temperature. This is therefore a significantly non-linear task because, even with the boundary conditions, their dependence on the surface temperature of the blank is respected here.

3 RESULTS

A real concasting operation casts up to several hundred grades of steel. It would therefore be difficult to set the concasting and other relevant technological parameters for all of them. A single grade of steel was selected from each group for the analyses below. Table 1 [3] contains the compositions of these steels, together with the temperatures of the liquidus and solidus. Figure 2 illustrates an example of the dependence of the thermophysical properties on the temperature for the P2-04B and C82DPC steel grade [1]. Figures 3 and 4 present the calculated temperature field for this grade of steel. These calculations were performed also for the remaining grades. In order to analyse the influence of the chemical composition on the temperature field more clearly, the other concasting parameters were selected identical, i.e. the casting speed 2.8 m/min, the superheating temperature 30 °C, just like the flow of water through the secondary-cooling zone. In practice, a different cooling mode is selected for each different grade of steel.

Tab. 1 Selected classes of steel with their compositions used for calculation

Steel	T_{LIQ}	T_{SOL}	C	Mn	SI	P	S	Cu	Cr	Ni	V	Ti
	°C	°C	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%
P2-04B	1531	1489	0,020	0,300	0,040	0,010	0,010	0,065	0,050	0,040	0,000	0,000
1220	1523	1477	0,100	1,025	0,075	0,010	0,010	0,060	0,075	0,075	0,015	0,000
TERMEX-1	1515	1457	0,180	0,725	0,200	0,020	0,020	0,200	0,075	0,075	0,000	0,000
C45EKL	1491	1402	0,460	0,650	0,300	0,0150	0,015	0,100	0,200	0,200	0,000	0,000
C82DPC	1466	1342	0,840	0,700	0,2000	0,0075	0,007	0,125	0,085	0,100	0,000	0,000

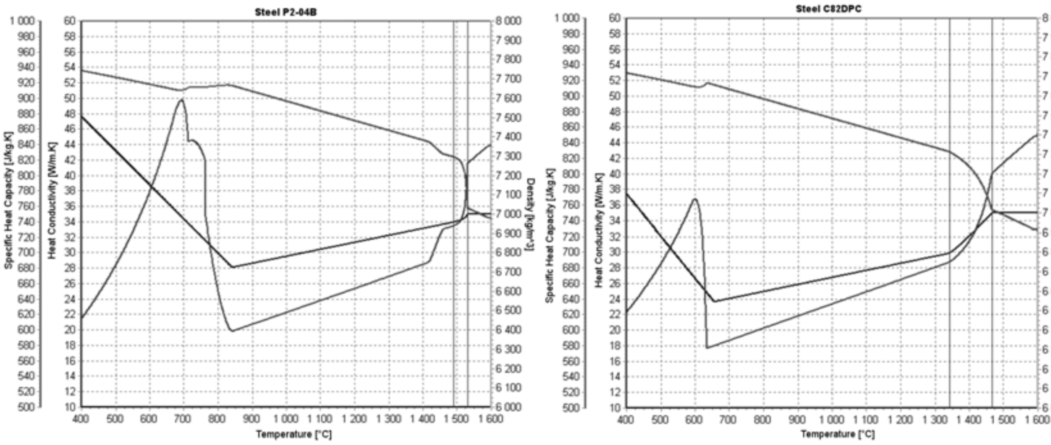
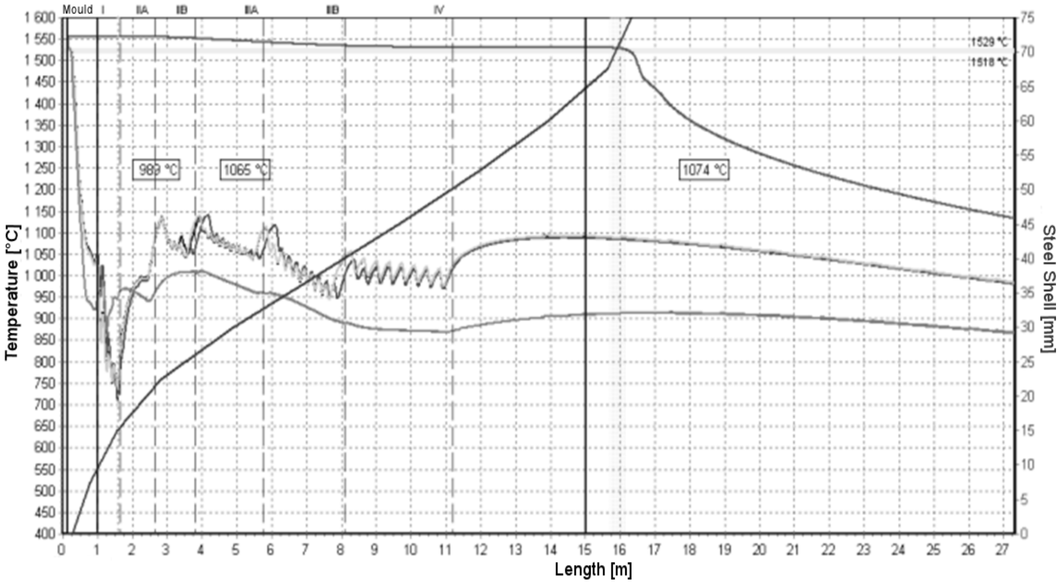
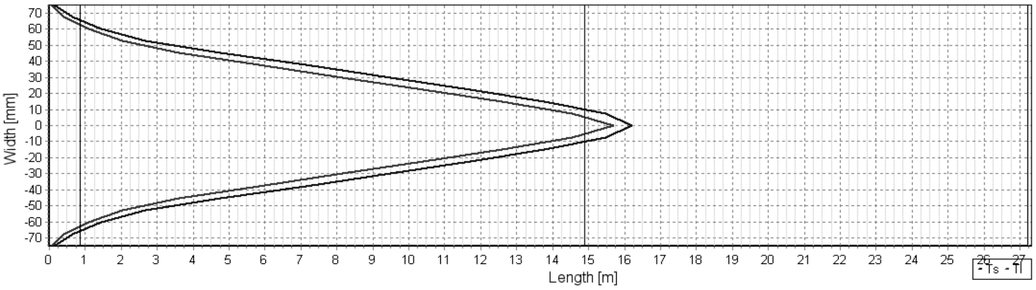


Fig. 2 Thermophysical properties of the P2-04B and C82DPC

Figures 5 and 6 summarise information on the output parameters. They show how the chemical composition of the cast steel influences the metallurgical length, length of liquid phase and surface temperature in the end of cooling zones. The lower content total carbon, the shorter the metallurgical length – this enables the introduction of a higher casting speed. Calculations proved that the effect of content total carbon on the surface temperatures is significant.

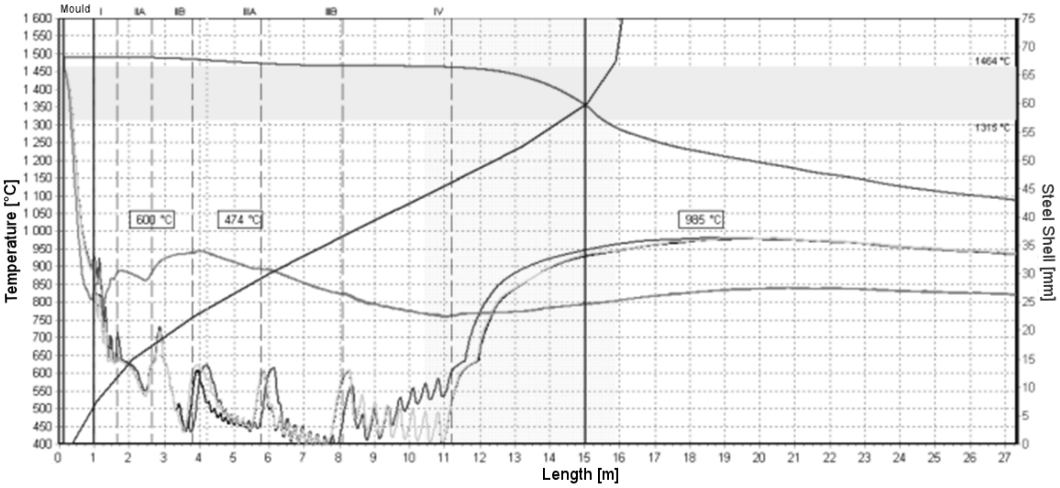


a) The course of surface temperatures and temperatures in the center of billet

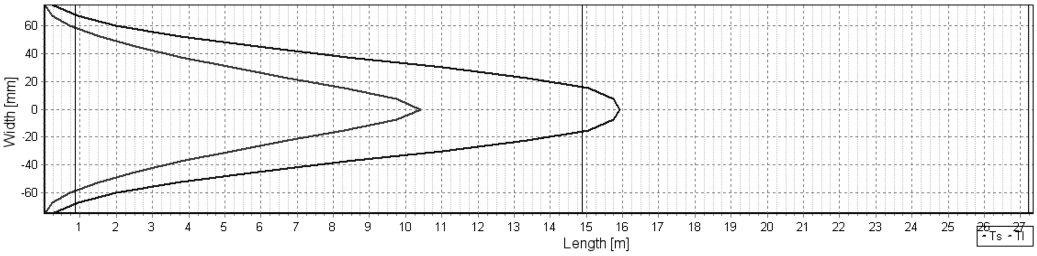


b) The course of temperatures of the liquidus and solidus

Fig. 3 Temperature field of the P2-04B



a) The course of surface temperatures and temperatures in the center of billet



b) The course of temperatures of the liquidus and solidus

Fig. 4 Temperature field of the C82DPC

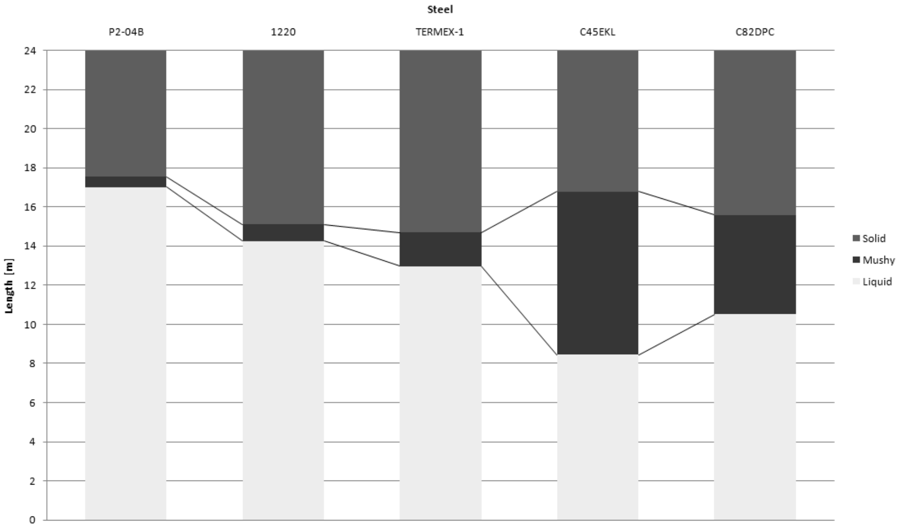


Fig. 5 Comparison of the length of the liquid phase and the metallurgical length for various classes of steel

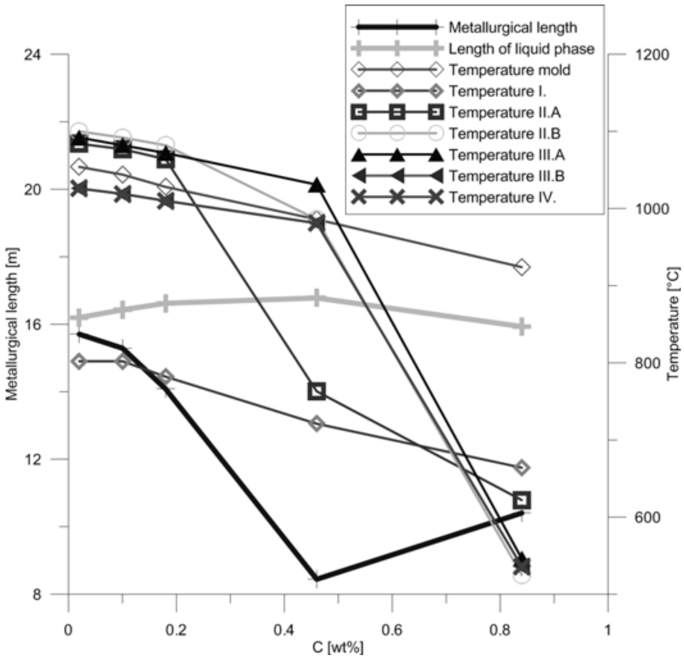


Fig. 6 The effect of the C content on the metallurgical length and surface temperatures

4 CONCLUSIONS

This paper introduces a 3D numerical model of the temperature field in the form of in-house software. The model includes the main thermodynamic transfer phenomena during the solidification of concasting. The temperature model is used for monitoring and for parametric studies of the changes in chemical composition of the concast billet.

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