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Numerical simulation of the temperature field of a concast steel blank

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Abstrakt: *Original numerical model was applied to the simulation of the temperature field of concast steel slab, when melt of steel of quality A finished and immediately the melt of quality B followed. In the secondary-cooling zone in the unbending point, the breakout of the steel can occur in points of increased local chemical and temperature heterogeneity of the steel. The temperature field of the slab was calculated for three variants of the chemical composition. The first variant is for the chemical composition of steel quality A, the second for the chemical composition of steel quality B and the third for the average chemical composition from quality A and quality B. The temperature model provides the temperature history of every points of a cross-section during its movement through the whole caster from the level of the melt in the crystallizer to the cutting torch, the course of isoliquidus, isosolidus and next isotherms, further temperature isozones. Heat transfer coefficient beneath the jets is given by the sum of the forced convection coefficient and the so-called reduced convection coefficient corresponding to heat transfer by radiation. The calculation also evaluates the metallurgical length and a range of mushy zone, i.e. zone between isosoliquidus and isoliquidus.*

1. Introduction

A breakout of the concast slab right under the mould is usually detected and indicated by an anti-breakout system. However, breakouts occur at contcasting, i.e. failure of strength of solidified shell even at smooth change of grade of the cast steel, most often on radial CCM at the place of straightening of the slab. This irreparable defect is moreover often initiated by surface defects, the origin of which is already in the mold during the beginning of crystallisation. These are oscillation marks and sub-surface pockets - hooks. Oscillation marks are transverse grooves forming on the surface of the solidifying shell of a concast slab. The hooks are solidified microscopically thin surface layers of steel [1-3]. They are covered with oxides and slag. Their microstructure is different to that of the base material of the solidifying shell. The formation of the oscillation marks and hooks are related. The depth of the oscillation marks and also the shape, size and the microstructure of the hooks vary irregularly. An increasing extent of these changes leads to a defect in the shape of a crack, which reduces the thickness of the solidified shell of the slab upon its exit from the mould and causes a dangerous notch.

In the secondary-cooling zone, where the slab is beginning to straighten out, the breakout of the steel can occur in points of increased local chemical and temperature heterogeneity of the steel. Especially dangerous are the changes in the chemical composition of the steel during the actual concasting. The consequences of this operational immediate change in the chemical composition of the steel, which are not prevented by a breakout system directly inside the mould, could lead to immediate interruption in the concasting and a breakout at a greater distance from the mould than usual.

2. Interruption of concasting

This case was recorded during the process of concasting of 250×1530 mm steel slabs of quality A and quality B (Fig.1).

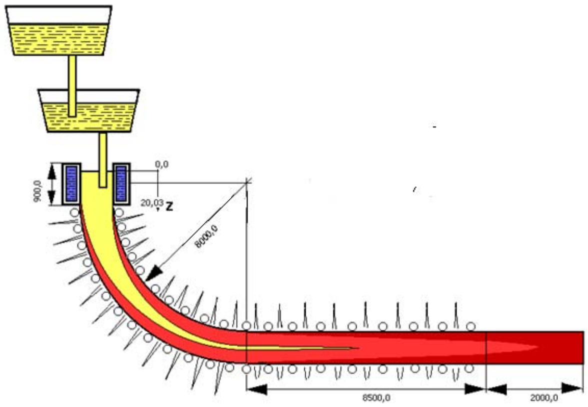

Fig.1: A slab caster

The change in the chemical compositions of the steels of both qualities was carried out very quickly by changing the tundish. Inside the mould, steel B mixed with steel A of the previous melt. The pouring continued another 20 minutes but then, after, in the unbending point of the slab, at a distance of 14.15 m away from the level of the melt inside the mould, there occurred a breakout between the 7th and 8th segments and the caster stopped. The difference in height between the level inside the mould and the breakout point was 8.605 m. This tear in the shell occurred on the small radius of the caster. A 250 mm thick sample was taken from the breakout area using a longitudinal axial cut (Fig. 2). a 0.41 wt. % carbon content and 9.95 wt. % chromium content (melts 1 to 3) and quality B steel with 0.17 wt. % carbon content and 0.70 wt. % chromium content (melt 4). Detailed chemical composition of both steels is in Fig. 3 and 4. The casting of the first two melts of quality A took place without any significant issues, after the casting of the third melt of quality A, the fourth melt of quality B followed.

Fig.2: A sample from the breakout area

3. Application of the numerical model on a concast steel slab

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.* In the first phase of the analyses, the aim was to determine the material, physical, chemical and technological parameters, which both melts 3 and 4 differed in.

Off-line version of the temperaturel model was used now to simulate the temperature field of steel slab of melt No.3 (steel quality A), steel slab of melt No. 4 (steel quality B) and a mixture of A and B quality. We consider that each thermophysical property (thermal conductivity, heat capacity, density and enthalpy) of the mixture A + B is the arithmetic average of the properties of steel A and B. The dependence of these parameters on temperature was observed [5].

The original model solves the temperature history of every point of the cross-section during its movement through the whole caster from the crystallizer to the cutting torch [4]. Fig. 3 shows the temperature curves of the slab cross-section for steel quality A, Fig 4 for steel quality B, Fig. 5 for steel quality A+B . In these graphs a curve shows also the grow of the thickness of a solidified shell .

For example calculated mushy zone (the area between isoliquidus – red – left curve and isosolidus - blue -right curve) in the the first and second axial longitudinal section for steel quality A+B is shown in the Figure 6

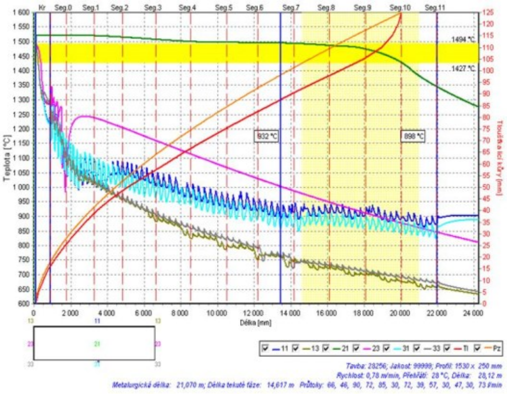

Fig.3: Temperature history of points of the slab cross-section . STEEL A wt% : 0.416 C, 0.95 Cr, 0.03 Ni, 0.70 Mn, 0.28 Si

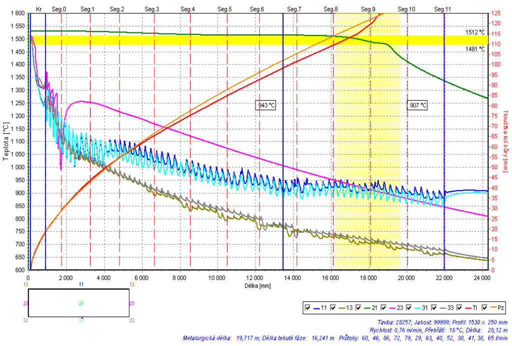

Fig.4: Temperature history of points of the slab cross-section. STEEL B wt%: 0.174 C, 0.07 Cr, 0.02 Ni, 1.46 Mn, 0.23 Si

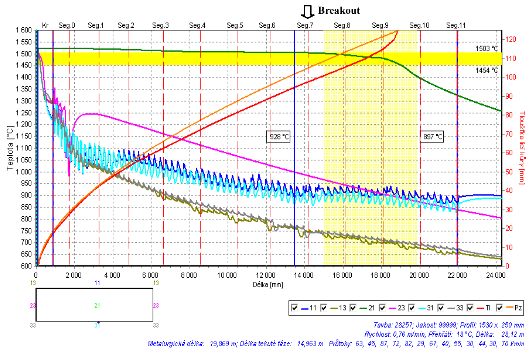

Fig.5: Temperature history of points of the slab cross-section (STEEL A+B)

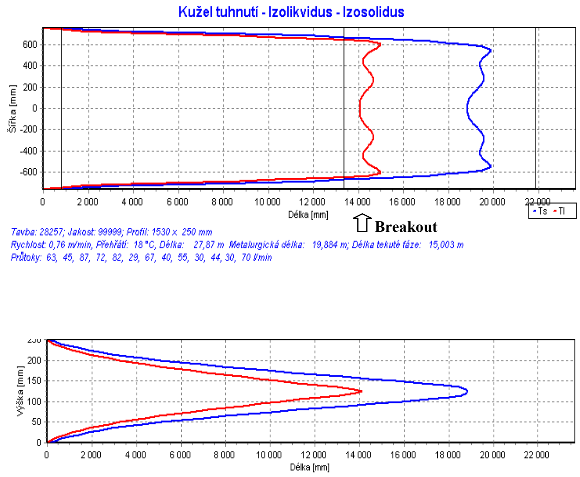

Fig.6: Isosolidus and isoliquidus in the first and second axial longitudinal section of the slab (STEEL A+B).

The calculated mushy zone in the cross-section of the slab in which the break out has occured (at a distance of 14.15 m from the level of melt in the mould) for steel quality A+B is shown in the Figure 7.

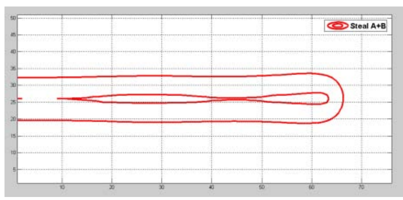

Fig.7: A mushy zone in the cross-section of the breakout (STEEL A+B).

4. The application of similarity theory.

Thermophysical parameters of both qualities of steel, technological parameters of the caster (casting speed, mold characteristics, etc.) and data that were obtained and collected by means of off-line model of the temperature field of the both slabs. Mutual dependence of the set of thus stipulated parameters and quantities will be determined. For this an application of theory of physical similarity is assumed. It is expected that this way will make it possible to reduction of the number of independent variables, describing individual partial processes accompanying continuous casting of steel slabs and also causal dependencies between these quantities. This is in principle the only possible manner how to describe, evaluate and control - in extreme cases – the stability of complex physical-chemical processes, from which the continuous casting is composed. That is to say that the existing findings and experience indicate that it is impossible, at least at present, to realise an absolutely exact mathematical-physical and chemical description of the whole process and control deduced from it – from the moment when liquid steel enters the tundish, including inter-mixing of individual heats, till the moment when steel enters the mold, its passage through the whole system of secondary cooling and zones of straightening till the final product. Application of similarity theory will be the subject of the continuation resesearch.

5. Conclusion

Formation of marks and hooks may lead under certain conditions, such as change of grade of contcast steel, to interruption of casting and to breakout Moreover the breakout occured after a quick change in the chemical composition of the concast steel quality A and the quality B. The change in the chemical compositions of the steels of both qualities was carried out very quickly by changing the tundish. The thermophysical parameters of both qualities of steel, technological parameters of the caster (casting speed, mold characteristics, etc.) and data that were obtained by means of off-line temperature model, were collected. Mutual dependence of the set of thus stipulated parameters and quantities will be determined. For this an application of theory of physical similarity and the derivation of similarity criteria is assumed.

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6. References

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