IMPROVING THE CASTING PROCESS OF PERITECTIC STEEL GRADES

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Abstract: *Longitudinal cracking when continuous casting of peritectic steels was studied in this work. Dependency of slab scarfing volume and surface cracking on the steel chemical composition was investigated. The optimum casting speed and taper parameter of the mold were determined based on analytical modeling and statistical analysis of surface cracks observed in industrial billets. It was shown that longitudinal cracks on peritectic slabs could be reduced when the Mn to S ratio was kept above ~150. Such surface defects were decreased to 30-35 % by optimizing the steel composition, melt temperature and casting speed. Also by using an optimum taper of the mold the scarfing volume was reduced to 32-36 %.*

KEYWORDS: *LONGITUDINAL CRACKS, PERITECTIC STEEL GRADES, MOULD TAPER*

1. Introduction

One of the most important components that is essential for the smooth operation of the continuous casting machine (CCM) and optimal quality of continuously cast billets, is the water-cooled mold which absorbs 10 % to 30 % of total the heat. Continuous casting of peritectic steels with about 0.1% C is particularly difficult since these steels are prone to the formation of longitudinal cracks and surface defects. Despite recent advances in the continuous casting technology, the quality of cast billets and their surface condition in a number of cases remain problematic; especially casting rolled products for critical applications.

The problem of improving the surface quality of continuously cast slabs with a mass fraction of carbon is close to 0.1%, and there is at present.

The mechanism of heat transfer between the billet and the mold is an important issue because the conditions of heat exchange depends on the performance of the caster and the quality of surface and subsurface layers of the cast billet. Understanding the mechanisms of heat transfer between the billet and the mold is essential for designing an optimum mold [1, 2].

Peritectic medium-carbon steels exhibit an anomalous decrease of the heat flux on the mold surface due to the surface roughness of the solidifying shells, whereas ultra-low carbon steels exhibit large heat flux despite their large surface roughness. Such difference is caused by the fact that the surface roughness of ultra-low carbon steels arises from δ/γ transformation which occurs somewhat later than the completion of solidification [3].

The degree of peritectic solidification is a strong indicator of the cracking tendency of steel during continuous casting. To predict the crack susceptibility of regular carbon steel slabs, the characteristic index of solidification shrinkage (RV), which is determined by the volume shrinkage of the peritectic solidification and the remaining liquid phase after the peritectic solidification, is proposed as a means of evaluating the cracking tendency [4].

Slight variation of C or Mn, in the order of 0.04%, promoted significant changes in the evolution of phases during solidification. The variation in the C content has a larger influence than that of Mn on the evolution of phases, however, the Mn microsegregation generated at high cooling rate can promote a change in the solidification mode from hypo to hyper-peritectic. Cracking susceptibility observed in the hypo-peritectic steel is not only generated by differences in the mechanical behavior δ and γ phases, but also by the liquid inability to compensate the contraction associated to the peritectic transformation [5].

The possibility of cracking increased with increasing sulfur content and the carbon content at which longitudinal surface cracking frequency is maximized decreased because brittle temperature range extended to the lower temperatures. The effect of the steel composition on the formation of longitudinal cracks using the non-equilibrium phase diagram has not been reported yet, and a more quantitative and systematic study must be made to interpret the surface cracking phenomena [6].

The cracks are usually curved (wavy) and vary in length from a few centimeters up to several meters in some cases. Longitudinal cracks are usually formed in the central part of the mold. The defects usually appear at the beginning of the continuous casting. The low carbon (<0.08%) slabs with > 1.1 % manganese sometimes have relatively short longitudinal cracks of about 100 mm long.

It is difficult to detect longitudinal cracks on the slabs immediately after casting. These defects are often associated with small inhomogeneities located near the surface of the slab. Previous research showed [7], leads to the formation of cracks. The probability of longitudinal cracks formation in the peritectic steels billets depends on the variation in the withdrawing speed [3].

Previous work showed that the formation of longitudinal cracks in the continuously cast peritectic steels was due to the volumetric change during δ to γ transformations [8, 9]. It was also shown that the formation of cracks can be reduced by (1) stabilizing slag penetration into the gap between the mold and the billet, (2) controlling the casting nozzle, and (3) reducing the time required to establish a steady casting speed.

It is also of interest to improve the surface quality of continuously cast billets by addition of surface-active elements and/or reducing the concentration of harmful impurities.

The chemical composition of the steel, particularly carbon content has a significant effect on the formation probability of longitudinal cracks, e.g. carbon concentration between 0.10 to 0.14 wt.%. is reported to be undesirable.

The tendency of crack formation in steels depends of on the ferritic potential F_p as defined in Eq. (1) [10]:

$$F_p = 2.5\ (0.5-[C_{eq}]), \tag{1}$$

where

$$C_{eq}= [\%C] + 0.04[\%Mn] + 0.1[\%Ni] + 0.7[\%N] - 0.14[\%Si] - 0.04[\%Cr] - 0.1[\%Mo] - 0.24[\%Ti] - 0.7[\%S]. \tag{2}$$

For fully ferritic steels F_p is above 1 (*e.g.* $F_p = 1.25$ for pure δ - iron). If $F_p < 0$, the steel is fully austenitic.

In addition, the taper and heat transfer condition have a significant influence on the formation of crack.

This paper presents the results of statistical analysis carried out on the formation of surface cracks by taking in account the overheating of the melt in the tundish and the mold taper when casting various grades of steels.

2. Experimental method

All of the studied steel grades melted in oxygen converter with a capacity of 350 tons, finishing on the chemical composition and refining were carried out on the ladle furnace.

The casting was performed on double-stream curved continuous casting machine producing slabs with cross-sections from 220×1250 to 250×1850 mm^2.

Experiments and quality control of continuously cast slabs was carried out for a wide range of steel grades with carbon concentration in the range of 0.08 to 0.19 wt.% and manganese concentration of 0.60 to 1.75 wt.%. Three types of steel samples were investigated in this work; plain carbon steels, microalloyed-steels with 0.03 to 0.05 wt.% of Nb, and microalloyed-steels with 0.02 to 0.04 wt.% of Nb plus 0.050 to 0.120 wt.% of V.

The total volume of investigated heats for analysis was 1800 heats.

3. Results and discussion

3.1. Statistical analysis of industrial billets

It is established that ferritic potential is quite sensitive to variations in the steel composition and can be used to predict the occurrence of surface defects in rolled products Figure 1 shows the results of a statistical analysis of the relationship between fraction of slab with longitudinal cracks and ferritic potential of corresponding heats. It is clear that the variation in the concentration of alloying elements significantly affected the amount of surface scarfing (see Fig. 1).

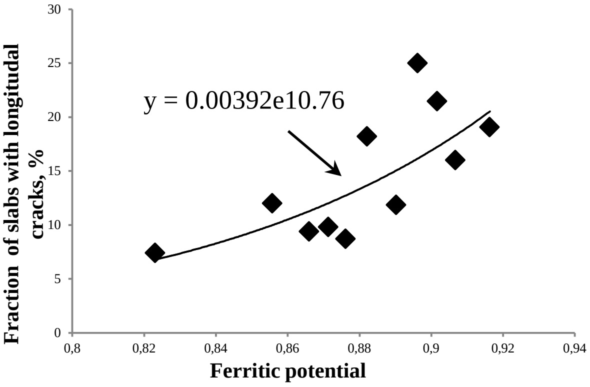

Fig. 1 - Influence of ferritic potential on longitudinal cracks in a peritectic steel grades, each point represents the average of 100 heats.

For example, an increase in the mass fraction of carbon from 0.11-0.12% to 0.13-0.14% decreased the volume of surface scarfing by third. For the steel with 0.14-0.16 wt.% carbon the optimal mass fraction of manganese was 1.35-1.50% (*i.e.* the largest value of Ferritic Potential). The decrease in the mass fraction of manganese to 1.23-1.35 % (at the same mass fraction of carbon) significantly affected the surface crack index.

In addition, the fraction of continuously cast billets with cracks increases with the sulfur content in the steel, because the formation of inclusions of manganese sulphide between dendrites depends on the ratio [Mn]/[S] (a typical example of the formation of manganese sulphide on the surface in dendritic spaces is presented in Reference [10]).

Fig. 2 shows the steel with a mass fraction of carbon over 0.12% (i.e. high Ferrite Potential) the amount of scarfing was increased and for a group of heats with high ferritic potential impact of the mass fraction of sulfur affects more.

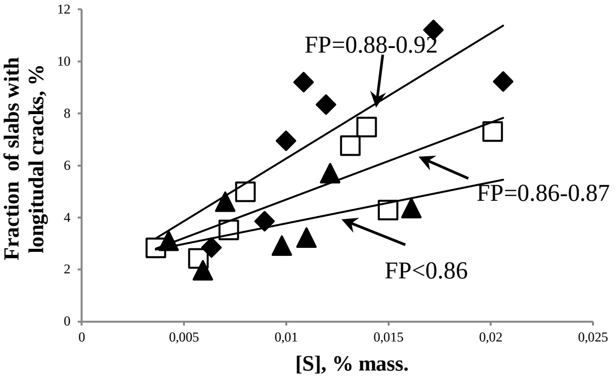

Fig. 2 - Effect of sulfur content on surface crack index in steels with various ferritic potentials.

On the basis of statistical analysis of industrial heats, shown in Fig.3, a manganese to sulfur ratio above 150 should be sufficient to substantially reduce longitudinal cracking in continuously-cast billets. A similar result, but less pronounced, was observed for correlation of the primary sorting slabs on longitudinal cracks and ratio [Ca]/[S].

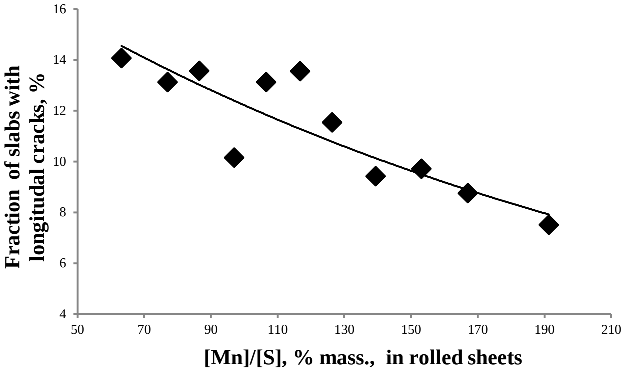

Fig. 3 - Influence of manganese to sulfur ratio on surface longitudinal crack index in peritectic steels, each point represents the average of 100 heats.

However, the possibility of varying the chemical composition of the metal is very limited; therefore, it is more practical to reduce the extent of cracking by optimizing the casting parameters such as the taper and heat transfer conditions in the mold.

Analysis of the continuous casting of peritectic steels using a curvilinear slab caster (220x1250mm to 300x1850 mm) showed that overheating of the metal in the tundish can increase the chance of longitudinal cracking (see Fig. 4). Thus, given the narrow range of chemical composition for this family of steels, it is advisable to reduce overheating in the tundish in order mitigate cracking problem. Additional benefit of reducing tundish temperate is having more uniform solidification of the shell.

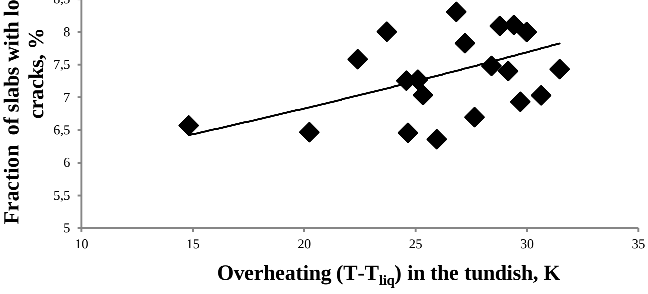

Fig. 4 - Effect of tundish superheating on surface crack index in a continuously cast peritectic steel billets, each point represents the average of 100 heats.

3.2. Calculation of optimal mould taper

However, changing overheating of the metal entails a change in the speed of casting. This is especially important for peritectic steel grades due to the strong dependence of the heat flux in the mold from the mass fraction of carbon with a sharp decline in it for peritectic steels [4].

Optimum casting speed, which depends on the heat flux and mass balance, can be estimated using the following equation (taking into account assumptions about the almost complete removal of overheating in the mold):

$$\mathrm{w} = \bar{q} \cdot \frac{2h_a}{\rho(Rc\Delta T+2xL)} \cdot \left(1+\frac{R}{b}\right), \tag{3}$$

where $\bar{q}$ is the mean heat flow extracted from the slab surface in the mold; h_a is the height of the mold; b & R are the width and the thickness of the slab; c is specific heat of the metal; x is the thickness of the solid shell and L is the heat of crystallization.

The Calculation was carried out using a modified dependence [11], in which the coefficient A is assessed by monitoring the heat flux in the crystallizer:

$$\bar{q} = A \cdot \left(\frac{R}{2}\right)^{0.11} \cdot \left(\frac{2\mu}{1+\mu}\right)^{-0.75} \cdot \mu^{0.3} \cdot \left(\frac{h_a}{w}\right)^{0.43}, \tag{4}$$

where μ is the aspect ratio of the cross-section of continuously cast billets.

The statistical analysis showed that the volume of surface stripping depends on the casting condition, withdrawing speed corresponds as of Eq. (3). By proper selection of withdrawing speed and using an optimum tundish temperature the longitudinal cracks in the slabs could be reduced by 30-35%.

An important factor influencing the longitudinal cracking in the slabs is the mold taper. As shown by statistical analysis of industrial heats, with careful selection of a mold taper, depending on the coefficient of solidification kinetics and slab width, amount of stripping was reduced by 30-35% Based on early work on the optimization of casting peritectic steel [3], the surface longitudinal crack index was reduced when using parabolic mold or a taper of 1.2-1.3 % compared with the conventional mold taper of 1.1%.

The taper of the mold must accurately reflect the change in the profile of the ingot caused by its shrinkage during solidification.

Assuming that the temperature of the metal in the cross-section solidified shell constant and equal to the average value between the liquidus temperature and the temperature on the shell surface, it is possible to calculate the optimal mold taper:

$$\mathrm{w} = \frac{l_{up}}{h_{kr}} \cdot \left(1 - \frac{1}{1+k\sqrt{h_c/v_{cast}} \cdot \left(\rho_{sol}/\rho_{liq}-1\right)}\right) \cdot 100, \tag{5}$$

where w is the taper of the narrow walls of the mold, %; l_{up} is the width of the upper section of the mold m; h_c, h_{kr} are the real metal layer height for calculation and height of the mold, respectively, m; ρ_{liq}, ρ_{sol} are density of liquid and solid steel, respectively, m^3/kg; v_{cast} is the casting speed, m/min; k is coefficient taking into account the kinetics of solidification of the shell (0.2-0.25), $min^{-0.5}$.

Hence, as of the statistical analysis of industrial heats, by correct selection of a cone mold, depending on the coefficient of solidification kinetics and slab width, the stripping volume reached 10-15%.

4. Conclusions

Based on analytical modeling and statistical analysis of the surface cracks observed in industrial billets, the optimum casting parameters for peritectic steels were determined The proposed formulas were used to optimise withdrawing speed and mold taper. The outcomes were crosschecked against the industrial tests.

Almost complete prevention of longitudinal cracks on slabs of peritectic steels and significant reduction of surface scarfing was achieved when the Mn to S and Ca to S ratios were above about 150 and 0.3, respectively.

The optimal values of the ferritic potential when casting peritectic steels with various carbon contents were determined. For steel without niobium the ferritic potential should be less than 0.88, whereas the steel containing 0.12-0.16% C, 0.08-0.12 and 0.10-0.14% C and 1.35-1.50% Mn - in the range of 0.76 ... 0 80, 0.80 ... 0.84, 0.86 ... 0.90, respectively.

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