# OPTIMIZATION OF SECONDARY COOLING DURING CONTINUOUS CASTING OF STEEL SLABS

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**Abstract**

The article describes an approach to decreasing the rejection rate of the steel plates due to the surface defects in the rolling mill achieved by optimization of air-water secondary cooling on the continuous casting machine (CCM) of steel. In context with the occurrence of the surface cracks on the steel plates a complex analysis of possible reasons causing the creation of monitored cracks was made. Control of all technological procedures, including setting parameters of the CCM, was introduced. On the basis of statistic evaluation of selected technological parameters and according to the occurrence of specific cracks on the steel plates, of which their character signalize the possibility to create the cracks due to effect of the secondary cooling, the calibration, nozzles replacement and adjustment of the casting parameters in this cooling area was performed. Optimization of secondary cooling adjustment was made for the steel grade S355.

**Keywords:** Optimization, continuous casting, secondary cooling, steel slab, surface defects

## 1. DETERMINATION OF REASONS LEADING TO DEFECTS ON CONTINUOUSLY CAST SLABS

The technological process of continuously cast steel slabs (CCS) production requires a deep knowledge of its thermomechanical and thermophysical properties, especially its strength and plasticity value in the range from its liquid phase to the solid phase. This also includes knowledge of temperature range since creation of the shell begins till the total slabs cross-section solidification and following strand shrinkage. Determination of the tensile strength and elasticity properties allow us to determine resistance of the steel against formation of defects and cracks. Strain in the CCS has a huge impact on the slabs quality as it can lead to a shape deformations and creation of the surface and internal defects of slabs, which are called high temperature cracks and low temperature cracks [1]. Slabs quality is characterized not only by its chemistry, but also by its shape and dimension accuracy. Another aspect of the CCS are its macrostructure and macro segregation in its primarily cast state. Primary dendritic structure is a picture of the crystallization process, steel chemical composition and the CCS casting conditions. Determination of the slab defect source might not be an easy task as some defects can have more sources than one; many times a deep analysis based on the CCS casting conditions or rolled products assessment is needed. Basic identification of the CCS defects can be divided into surface defects, internal defects and inaccurate slabs dimension [2]. Change in technological parameters leading to the CCS defects can be divided into several groups - technological parameters of casting, primary and secondary cooling of the strand, the CCM technical condition and the steel chemical composition. Adjustment of the secondary cooling must follow the adjustment of the primary cooling in order not to allow the strand to undergo the rapid thermal changes. Secondary cooling adjustment must be provided deliberately as a rapid temperature change can lead to a rupture of the slabs shell, leading to the breakout, or just to the worsening of the slab surface quality. Creation of the surface defects can be caused by the cooling intensity after the strand output from the mould, it can also occur during the strand unbending. In the area of the secondary cooling change and re-heating of the strand, the strain change occurs, leading to the shape deformation and creation of surface and internal defects. Every strand is affected by the strain since it is cast till it is totally cooled down [2]. If the CCM radius and thickness of the strand ratio is not optimized and thus the strain in the outer radius is excessive, surface cracks can occur in the unbending zone. These cracks are usually visible only on the final rolled products/steel plates. Cracks, which cannot be observed on the slabs surface, can be hidden under a layer of scales [2].

## 2. SURFACE DEFECTS SOURCES ANALYSIS

After an excessive amount of the slabs surface defects was observed, an analysis of casting conditions and technological procedures was performed. The defects can be caused by insufficient checks and maintenance of the secondary cooling pipelines and spray nozzles [3], [4], one source of the surface defects being also the secondary cooling adjustment. The secondary cooling adjustment and tuning is also done when new steel grades are produced. The analysis showed that for the grade S355 there were 3 defects identified:

- scale defect caused by a casting powder affected the first heats in a sequence
- a deep crack defects
- star shape transversal crack

During the observed period with high amount of the star shape crack occurrence, the analysis of 92 heats was conducted as out of these heats 610 664 kg of steel plates were rejected. Possible source of the cracks was the secondary cooling zone of the strand. Detailed analysis was focused on the technical parameters of the casting - the pressure and flow-rate on each secondary cooling circuit with dependency on the casting speed and its impact on the strand surface temperature. Temperature of the upper side of the strand before its input to the segment No.7 in the unbending zone is highlighted by green color for the CCS without defects and in blue for the CCS affected by the star shape defects. The surface temperature curve is in the picture **Fig. 1**.

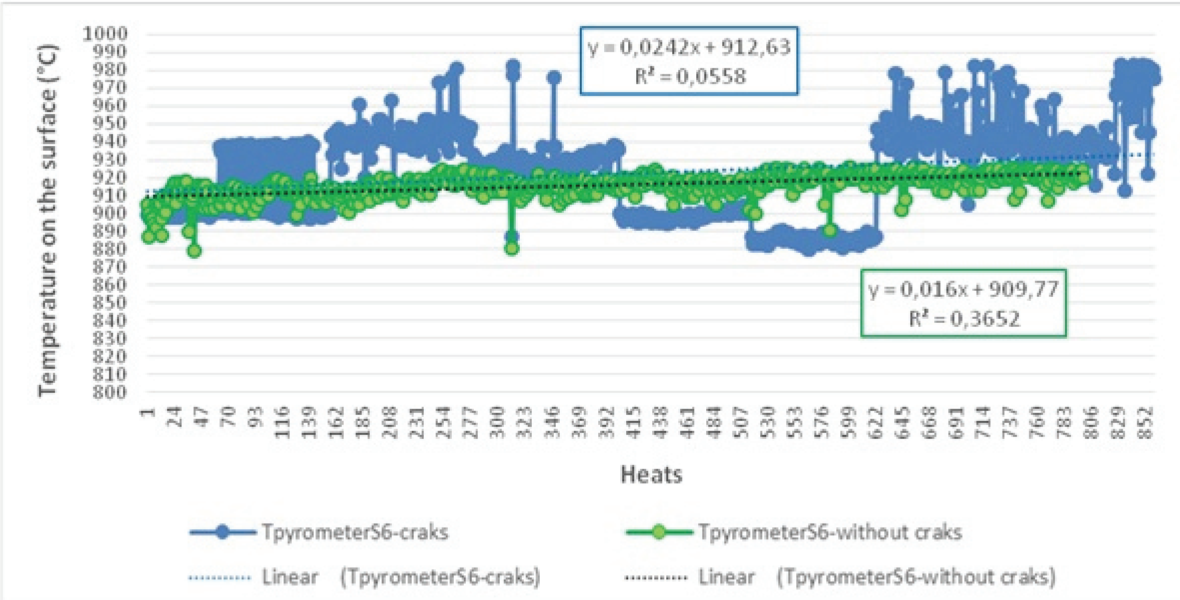



**Fig. 1** The surface temperature of the strand

## 3. SECONDARY COOLING TECHNOLOGICAL PARAMETERS OPTIMIZATION

The secondary cooling adjustment is dependent on the primary cooling in the mould so that no rapid temperature changes occur; in the zone of the surface cooling change and the strand re-heating, the strand strain changes. The strain changes can then lead to a shape deformation, surface and internal defects.

Knowledge of the thermal field of solidifying and cooled strand allows us to analyze and predict the possible shell rupture, slabs internal structure, surface quality, mechanical properties of the slab and lets us also optimize each parameter of the technology. If we omit the mass transfer in the mould and consider thermal conduction as dominant, then the problem is reduced on solving of Fourier-Kirchhoff equitation. Heat source during the strand cooling is - in the phase change in case of cooling - followed by releasing of latent heat. As in case of steel the phase change latent heat Lf is constant, a solid phase content fraction is function of temperature, thus (1), [1]:

$$Q_{source} = \rho \, . \, Lf \, . \frac{\partial fs}{\partial t} \qquad (1)$$

where Lf is latent heat of the phase change (J), $\rho$ - steel specific weight (kg.m$^{-3}$).

In case of the calculation of thermal field of the strand processed through the primary, secondary and tertiary cooling, the field can be described using Fourier-Kirchhoff equation reduced to the longitudinal direction of the velocity vector.

$$c \; v. \left(\frac{\partial T}{\partial t} + w_z \frac{\partial T}{\partial z}\right) = \frac{\partial}{\partial x}\left(\lambda . \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda . \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(\lambda . \frac{\partial T}{\partial z}\right) + Qsource \qquad (2)$$

Equation (2) describes the thermal field of the strand during its three phases:

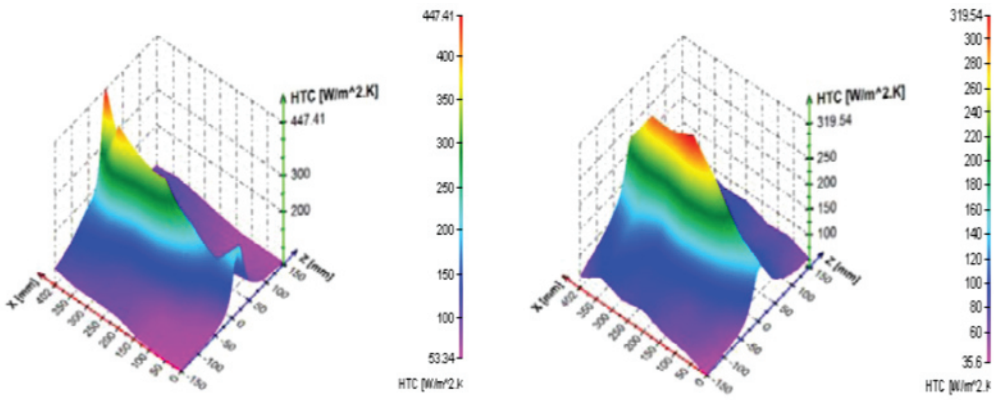
a) over the liquid temperature in the melt
b) in the range of liquid-solid solution (mushy zone)
c) below the solid temperature

3D modelling calculation is based on the finite derivatives method. The model has graphical interface allowing automated generation of the net for optional mould shape and the slab cross-section.

In order to lower amount of the surface defects, it was recommended to increase the surface temperature in the unbending zone over 900°C and to introduce a more homogenous cooling. The recommendation was based on the numerical modelling outputs and simultaneous adjustment of the cooling parameters in the temperature model.

Water flow rate to each spray nozzle was on the level 2.2 - 2.5 l.min$^{-1}$. It was discovered that by the secondary cooling adjustment, meaning its lowering, we will get to the lowest limits possible for the used nozzles type 100.638. To be able to achieve the strand surface temperature higher than 900 °C in the unbending zone, the characteristic of lower type line 100.528 was measured and mathematically modelled.

Experimental determination of the nozzles characteristic and their calibration is performed in a laboratory [1], [2]. By comparison of heat transfer coefficient (HTC) for each nozzle type it was discovered, that current nozzles 100.638 have higher cooling effect with less homogeneity (**Fig. 2a**) than the new type of nozzles (**Fig. 2b**). New nozzles type 100.528 cool off less by 10 - 20% using the same amount of water than the old type 100.638. In the **Fig. 2a** and **Fig. 2b** calculations of the HTC for both nozzle types are displayed:




a) Old nozzle type 100.638 b) New nozzle type 100.528

**Fig. 2** Water flow-rate comparison of old and new nozzle type

Current nozzle type 100.638 showed that with higher wear and tear it increases the cooling effect. Based on the executed calibration of each type of nozzle, a mathematical calculation was performed, which led to the recommendation to replace nozzles installed on the upper side of a couple of segments. Another recommendation was to increase the air pressure on each separated circuit and lower amount of water being used, which led to decreasing of the cooling effect and increasing of the strand surface temperature.

## 4. TECHNOLOGICAL PARAMETERS OPTIMIZATION POSSIBILITIES

After replacement of the upper nozzles of the arc pulling segments, the adjustment of the water-air-pressure ratio was verified by displaying trends of each cooling circuit a temperatures of the strand calculated by the model. Comparison of the before/after trends allows us to evaluate impact of the nozzles replacement on the secondary cooling trends, or in the temperature model.

One of the examples of the technological parameters optimization is displaying of the eater pressure and flow-rate ratio of the segments No. 4 and 5 in the picture **Fig. 3**, where the nozzles were replaced. The red trend shows positive effect of moving to the soft cooling in comparison with the current trend in blue.

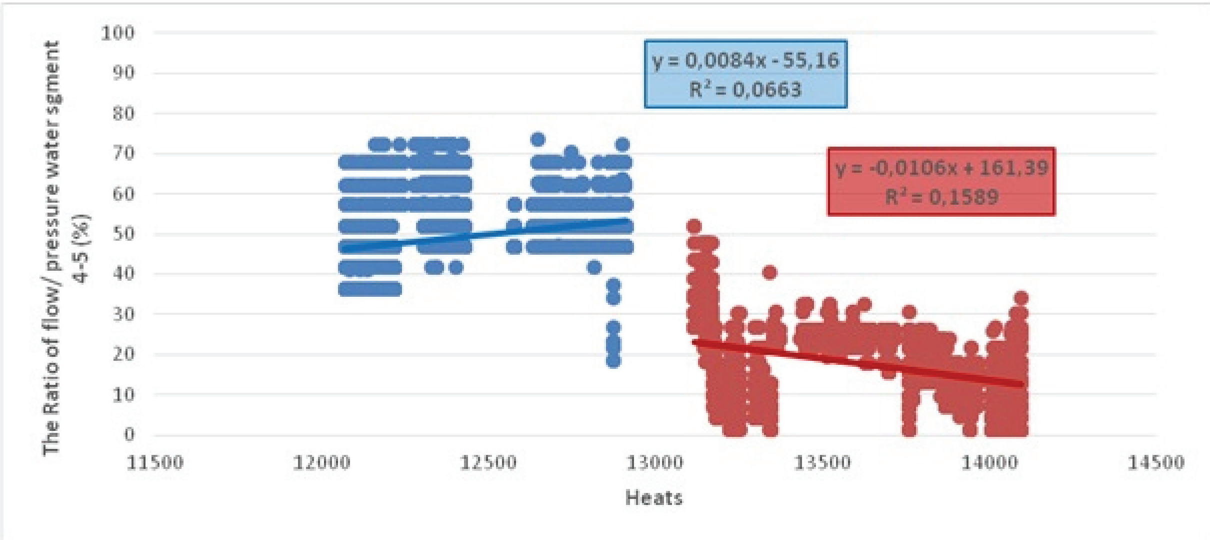



**Fig. 3** Segments 4 and 5 trend before/after the nozzles replacement

Based on the database file of each cast sequence it is possible to statistically evaluate and search for the dependency and influence of each technological change [3]. Dependency of each technological change can be displayed and evaluated according to the steel grades, casting speed, surface temperature, mould steel level and another 450 values [4].

## 5. CONCLUSION

Prior to the secondary cooling optimization was the increasing amount of the rolled products surface defects, which had to be re-worked or even, rejected. To improve the situation, the secondary cooling was adjusted, but the current options of the adjustment were very low. To lower the amount of defects, it was recommended to increase the unbending zone temperature over 900 °C and homogenous cooling was also required. This recommendation was based on the numerical modeling and calculations based on current adjustment of the temperature model. To achieve the higher temperature, the nozzles types 100.638 and 100.528 cooling characteristic were measured. After the nozzles replacement, first analysis was performed showing stable trends of real-life production values without significant deviation.

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