

## CAUSES OF OCCURRENCE OF INTERNAL AND SURFACE DEFECTS AT CONTINUOUS CASTING OF STEEL SLABS AND POSSIBILITIES OF THEIR REMOVAL

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### Abstract

The paper was focused on search of causes of occurrence of internal and surface defects of continuously cast steel slabs. The relationships between types of defects given in literature and their occurrence in industrial practice were investigated, ensuing from preparation of the melt according to the specification of secondary metallurgy unit and equipment of the continuous casting machine. Methods leading to the analysis of causes of formation of defects at non-observation of standard of metallurgical and technological procedures are always complicated and time consuming. The paper defines occurrence of individual types of defects and possibilities, which were developed for their removal in the BOF shop with single strand slab continuous casting machine.

**Keywords:** continuously cast steel, internal defects, surface defects, analyses, causes

### 1. INTRODUCTION

Operation of the company EVRAZ VÍTKOVICE STEEL a.s. represents production units with two oxygen converters followed by secondary treatment unit with ladle furnace and two caissons with oxygen lance and with subsequent casting of steel slabs. Quality of slabs significantly affects and determines the quality of the final rolled products and thus the economics of the entire production process of steel processing. Quality of slabs is then determined by the state of molten steel ready for casting, by conditions of casting technology and by condition of the casting machine. Technological processes of casting and condition of the casting machine can be assessed from the perspective of many different parameters. However, in operational practice it is not always possible to unambiguously determine the degree of influence of these parameters on the character of casting or occurrence of specific defect in the continuously cast steel slab (CCSS).

### 2. CAUSES OF FORMATION OF DEFECTS IN CONTINUOUSLY CAST STEEL SLABS

Basic characteristic of possible causes of formation of individual defects in continuously cast steel slabs can be given in accordance with technical literature [1, 2]:

- Chemical composition of steel
- Influence of technological parameters of casting
- Influence of primary cooling
- Influence of secondary cooling
- Condition of continuous casting machine

Technological parameters or basic nodal points of continuous casting can be, however, of more general character and they may influence whole groups of the mentioned defects. Occurrence of individual defects in continuously cast steel slabs and their frequency are related also to specific conditions of the steel shop, particularly the state of the continuous casting machine. Their subsequent processing can also significantly influence their occurrence. Formation of these deformations is then gradually transferred to the rolling mill, to the final product - plates or sheet piles.

Description of types of defects of continuously cast steel slabs in dependence of the character of their location on their cross-section for determination of analysis of technological-metallurgical influences occurring on CCSS must be performed in dependence on their character, which has the following basic classification [1, 2]:

- a) Defects of dimensions and shape
- b) Surface defects
- c) Internal defects

On the basis of knowledge of possible origins characteristics relationship with formation of individual defects in continuously cast steel slabs it is possible to influence their occurrence.

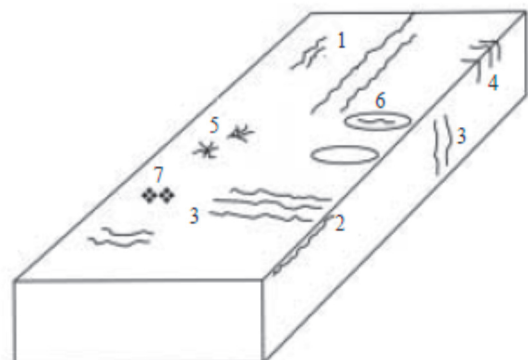
### 3. COMPARISON OF DEFECTS DESCRIBED IN LITERATURE WITH DEFECTS OCCURRING IN METALLURGICAL PRACTICE DURING CONTINUOUS CASTING OF STEEL SLABS

Due to extensiveness of this topic, i.e. defects on steel slabs, we focused only on surface defects. These deformations are concerned directly with the surface of slabs. During production of CCSS the biggest problem of continuous casting from the perspective of quality concerns the surface defects, which cause mostly significant problems during subsequent processing of CCSS, than defects of shape or internal defects [2]. It is given by the fact that consequent rolling does not eliminate all defects on the CCSS surface and they continue to manifest themselves as defects on surface of flat products, where the requirement for perfect state of surface is of utmost importance. Frequency of occurrence of surface defects is also during continuous casting of steel slab mostly much more frequent, than frequency of occurrence of another defects. The surface defects can be divided into two groups, namely discontinuities of the type of cracks and bubbles. These defects are characterised by damage of solidified strand shell continuity that was formed by pressing of non-metallic material onto the surface of CCSS, by penetration of steel between the mould wall and solidified strand shell of CCSS, by interruption of casting, etc.

The formation of surface defects in CCSS are caused by production technology - particularly by chemical composition of steel, by technical condition of the mould and by technological parameters of casting, casting temperature, casting speed, condition of secondary cooling and the rolls and segments allignment. It is then possible to specify some typical surface defects, which occur on continuously cast steel slabs:

- Longitudinal surface (1) or corner cracks (2),
- transverse surface (3) or corner cracks (4)
- star cracks (5) and transverse depressions
- longitudinal and transverse depressions (6)
- deep oscillation marks with solute segregation
- bleeding
- clusters of inclusions (7)
- slag patches or entrapped slags/scums, and gas holes, including blowholes and pinholes.

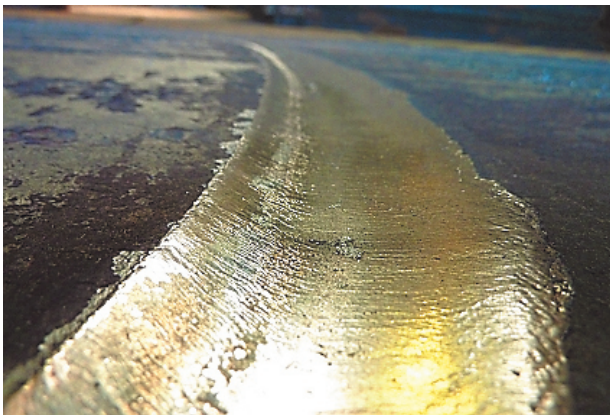
Schematic diagram in **Fig. 1** presents some typical surface defects of CCSS, which occurred in metallurgical practice [2].



**Fig. 1** Diagram of surface defects on CCSS

#### 4. DEFECTS OF THE TYPE OF TRANSVERSAL CRACK OF ZIP CHARACTER

Special example of defects occurring in metallurgical practice, which were the most frequent, were the defects of the type of transversal cracks of zip character. These defects occur not directly on the surface, but only after technological operation consisting of regular removing of surface layer from the final continuously cast steel slab by flame for control purposes, i.e. after removal of a strip of approx. 50 mm across the CCSS into the depth of 2 - 3 mm. The surface temperature for visual control of the continuously cast steel slabs must be then around 100 °C. During the process of removal of the layer by flame it is possible to observe the occurrence of this crack defect in the CCSS difference in light. **Fig. 2** shows realisation of surface layer removing from the final continuously cast steel slab by flame. Surface temperature of CCSS is very important during the control of the state of the surface, since at higher temperature it may be possible to overlook these defects.



**Fig. 2** Removal of surface layer from the slab



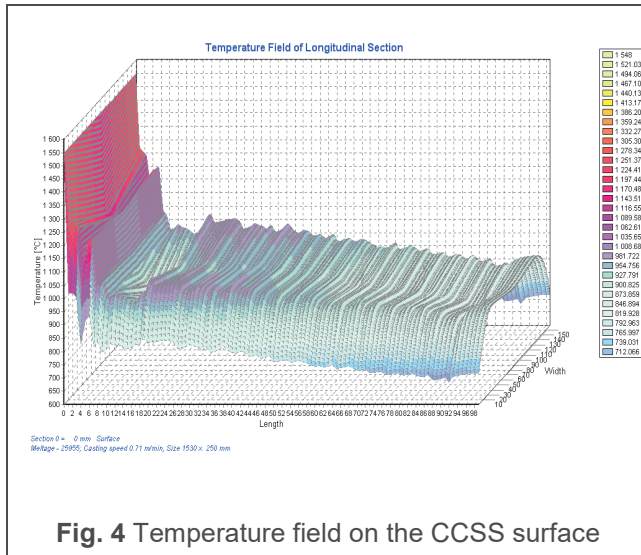
**Fig. 3** Determined defects on sheets

If these defects are not removed from produced CCSS, they may appear on the surface of sheets of final products. **Fig. 3** shows an example of these defects transferred from CCSS to the surface of sheet of final product. Technological procedures solved originally prevention of formation of these surface defects for selected grades of steel and cast sections of CCSS by complete disposal of the slab. Due to the high costs these production technologies were gradually optimised. Research and development of prediction systems for control of the entire production process was based on basic parameters including chemical composition of steel, casting temperature, casting rate, technical condition of the mould, technological parameters of casting, condition of the secondary cooling equipment, the rolls and segments alignment, etc.

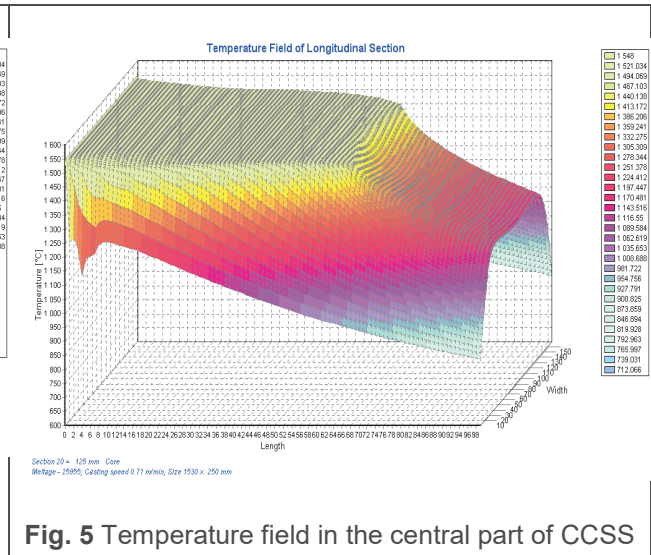
Evaluation of quality of slabs on the continuous casting machine makes nowadays part of the information system of CCSS [4]. This software system is organically connected with the on-line temperature model, as well as with the on-line module for data reading. Consequently a complex system of long-term monitoring of casting parameters and their influence on slab quality was progressively implemented, which makes part of the off-line model LITIOS, which records approximately 400 parameters of the continuous casting machine per each 1 m of the slab length. [3].

Prevention of formation of transversal crack defects of zip character requires not only observation of stipulated standard technological parameters, but also for example stable perfect condition of the primary and secondary water-air cooling systems of CCSS. If the temperature in the casting arc and the place of straightening is too low, then it is possible to increase it by modification of parameters of water-air secondary cooling. Literature specified that recommended optimal surface temperature at overheating of continuously cast steel slab at the place of straightening is above 900 °C [3]. **Fig. 4** shows an example of temperature field of the CCSS surface

and **Fig. 5** gives an example of temperature field of central part of CCSS. Since the erection of the continuous casting machine certain modifications were gradually made in production technology in order to achieve the temperature of CCSS at the place of straightening higher than 900 °C for certain groups of steel grades and sections of CCSS, specifically on the secondary cooling equipment [4].



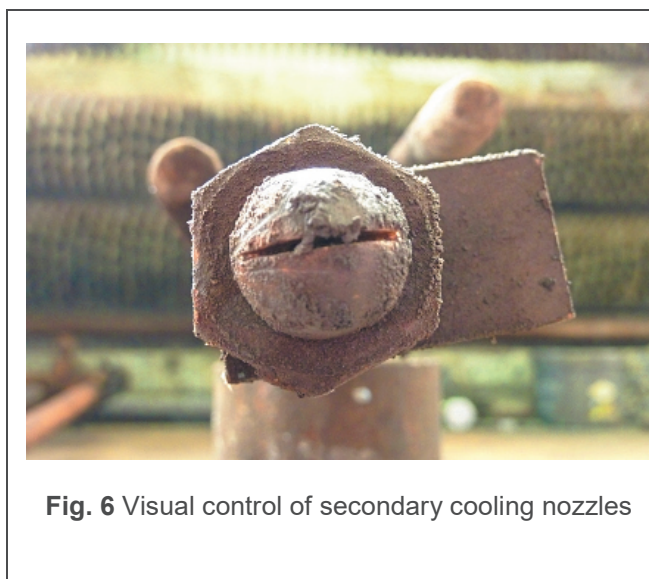
**Fig. 4** Temperature field on the CCSS surface



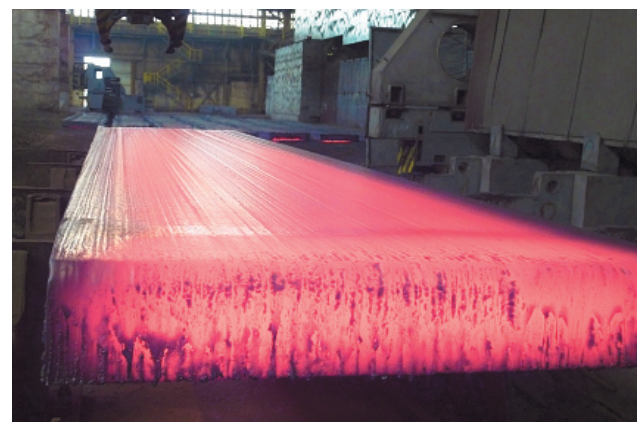
**Fig. 5** Temperature field in the central part of CCSS

Important role in metallurgical practice is played also by the system of preventative maintenance, and for the area of secondary cooling of CCSS it is for example the required standard technical condition of the nozzles. **Fig. 6** illustrates the nozzle of secondary cooling after visual control before repair.

Another important factor significantly related to the level of secondary water-air cooling concerns also individual steel grades groups for casting of CCSS. This concerns namely the group of peritectically solidified steels, where the probability of cracks occurrence is much higher, especially for the steels with carbon contents from 0.1 to 0.18 %. Technical literature says that the most important metallurgical factors of cracking of cracks formation on CCSS are: coarse austenitic grain, a precipitates of sulphides and oxides on the boundaries of dendrites or austenitic grains, and macroscopic tension, induced by voluminal changes at solidification [2].

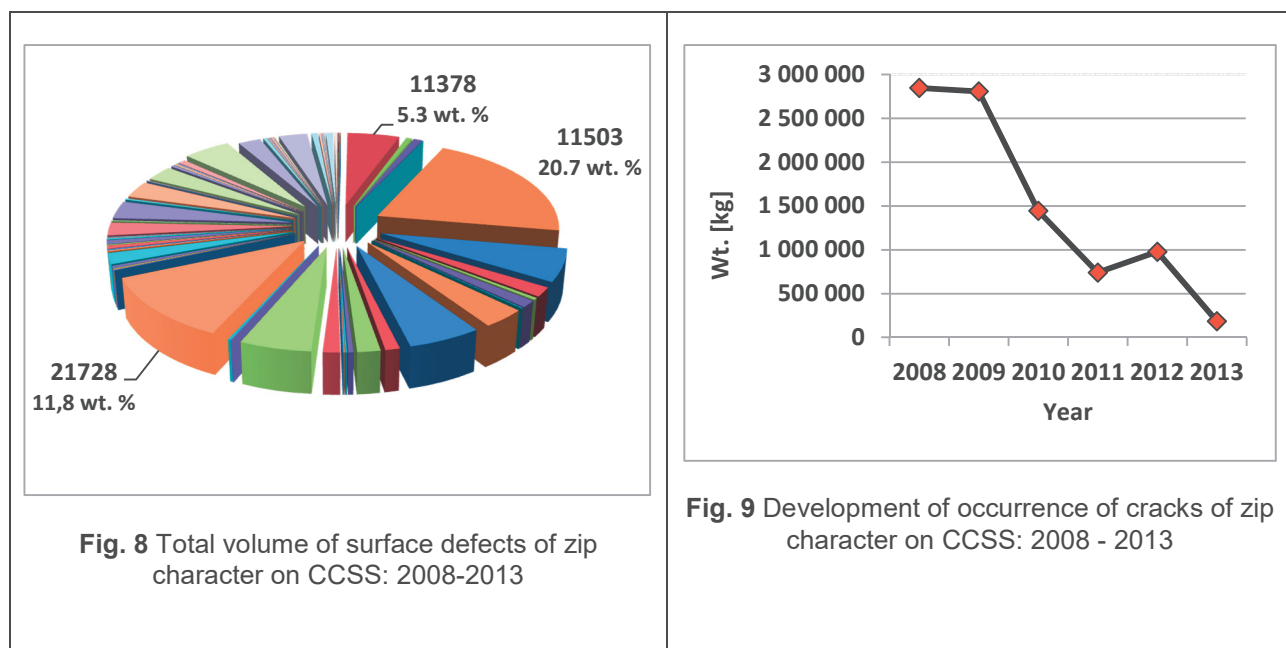


**Fig. 6** Visual control of secondary cooling nozzles



**Fig. 7** View of scarfed surface of CCSS

To achieve the maximal quality of produced CCSS, the parameters on-line monitoring and evaluation is performed during the whole casting of a sequence, according to the quality prediction system, which directly influence the continuously cast steel slab quality. If any deviation is found from the stipulated technological standard, which may negatively influence the CCSS surface, it is possible to send such continuously cast steel slabs for cleaning of the top surface to a scarfing machine, which uniformly cleans the CCSS surface by flame in a depth of at least 1.5 - 3.5 mm according to the predicted seriousness of the defect. **Fig. 7** shows an example of view of the scarfed CCSS surface. Commissioning of the scarfing unit for CCSS in the year 2009 influenced zip character cracks occurrence ratio, which is illustrated by the curve covering the period from 2008 to 2013 in **Fig. 9**.



**Fig. 8** Total volume of surface defects of zip character on CCSS: 2008-2013

**Fig. 9** Development of occurrence of cracks of zip character on CCSS: 2008 - 2013

There are more than 200 steel grades cast in the EVS steel shop. **Table 1** presents an example of chemical composition of selected grades of steel. **Fig. 8** illustrates for selected grades of steel total occurrence of zip character surface defects on CCSS in the years 2008-2013.

**Table 1** Example of chemical composition of selected grades of steel

Metallurgical designation	Steel grade	C [wt. %]	Mn [wt. %]	Si [wt. %]	P [wt. %]	S [wt. %]	Al [wt. %]	Nb [wt. %]
V235	11378	0.12	0.45	0.25	max.0.025	max.0.015	0.030	
V355	11503	0.17	1.40	0.35	max.0.020	max.0.005	0.035	0.030
V355	21728	0.17	1.45	0.35	0.020	max.0.008	0.040	

Continuous reduction of surface defects occurrence is a permanent goal, since in final production every scrapped sheet represents economic loss. Machines for casting of CCSS have in the following rolling mills a wide assortment of products - plates and sheets of various thickness. Increase of production costs depends significantly also on the fact, whether the occurrence of surface defects is on the steel sheet with thickness of 8 mm or 50 mm. The basis for permanent reduction of occurrence of the zip character surface defects will always be prediction information systems, which are functionally connected with an on-line temperature model, as well as with the on-line module from data reading. In direct connection it will be necessary to continuously optimise scarfing technology for CCSS depending on steel grades, cast sections of CCSS, on-line results of prediction systems and with use of statistical off-line model LITIOS. In spite of that the correctly set and applied system of preventative maintenance of continuous casting machine will also always be an important element.

The following may serve as examples of preventative controls and replacements:

- Replacement of the mould, worn corners on mould Cu plates, which may cause corner cracks on CCSS.
- Replacement of cracked hose in the secondary cooling water or air circuit, clogged nozzles, which may cause non-even cooling of surface.
- Visual control after each sequence can prevent deformations of shape. Worn out rolls in segments of the casting arc or excessive residues of scales between segments, etc.

Finding causes of surface defect formation is usually complicated. Setting of standards in the entire area of production technology and their observation creates only preventative measure for a never ending work aimed at prevention of the defects formation.

## CONCLUSIONS

The aim of this article was to make comparison of formation of surface defects described in professional literature with their practical occurrence in metallurgical operation on machine for continuous casting of slabs. Due to the extensiveness of the issue of surface defects we specified conditions for formation of surface defects with the largest occurrence, i.e. of the zip character type of transversal crack, methods of preventative measures decreasing their formation and possibilities of their elimination, systems of prediction of defects occurrence and necessity to apply preventative maintenance of the continuous casting machine [3, 4]. We gave some practical example of exploration of the causes leading to formation of the zip character transversal crack on the continuously cast steel slab.

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