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STUDY ON THE INFLUENCE OF CONTINUOUS CASTING PARAMETERS ON QUALITY OF SEMI-FINISHED PRODUCTS

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Abstract: *In today's siderurgical industry, more than 99% of the global steel production is made using two types of metallurgical facilities, i.e. oxygen converter and electric arc furnace. Worldwide, for both types of processes, there are several versions of construction and key technology, but the basic principle is maintained in each case, i.e. intensive use of the oxygen in oxygen converters and of electricity in the electric arc furnaces. Regardless of the steelmaking method/facility, more than 99% of the entire steel production is cast using the continuous casting method, and not more than 1% as ingot (destination: steel forging, tool steels, etc.). This paper deals with the influence of continuous casting parameters on the quality of semi-finished products, i.e. chemical composition, steel casting temperature, casting speed, drawing and solidification, and the billet cooling parameters influence on the defects generated during casting, solidification and cooling.*
Keywords: *steel production, steelmaking method, continuous casting, parameters, semi-finished products, quality*

INTRODUCTION

The continuous casting producing steel billets, compared with the conventional casting method, has a number of technical and economic advantages, as follows [1, 2, 3, 4, 5]:

- ✓ Increases the metal yield from 83-85%, obtained at the classical casting methods (ingots), to minimum 96% (sometimes more than 99%) at sequential casting;
- ✓ Reduces the consumptions of energy (electrical and heat energy), refractories and manpower;
- ✓ Reduces the investments;
- ✓ Increases the productivity and reduces the manufacturing costs.

The continuous casting, compared with the classical casting method, imposes a stricter observance of the casting parameters, especially when the section of semi-finished products decreases.

The continuously cast billet quality is determined by several steel making & casting parameters, as follows [1, 2, 3, 4, 5, 6, 11]:

- ✓ The steel chemical composition that is prescribed and must be observed, and according to which the casting parameters are selected;
- ✓ At the continuous casting, in order to avoid the formation of internal defects, the sulphur content must be very well correlated with the manganese content, and also the hydrogen and nitrogen contents;
- ✓ In order to avoid clogging of the immersion tube with Al_2O_3, the aluminium content must be kept as low as possible;
- ✓ The steel casting temperature, from the ladle into the tundish and from the tundish into the mould;
- ✓ The specific consumption of heat insulation powders in tundish;
- ✓ The specific consumption of ointment powders in the mould;
- ✓ The parameters of cooling water, (flow, pressure and temperature);
- ✓ The speed of casting, solidification and drawing;
- ✓ The constructive parameters of the continuous casting facility.

The inconsistency of the casting parameters with the prescribed limits leads to the generation of defects, therefore affecting the quality of the billets.

STUDY OF THE PROBLEM

In contact with the cold walls of the mould, there is a strong cooling of the steel to a depth of 140 ... 200 mm below the level of the liquid steel, when there is rapid growth of the marginal crust with fine uniform and equiaxed crystals, forming the first solidification zone. When passing away from this distance, the crust detaches from the mould walls, and up to the exit there is a slow cooling, due to the insulating air space. Thus appears the second solidification zone, or the intermediate zone containing columnar crystals [2-4, 6, 11, 12]. This area is much less large compared with the area afferent to the conventional casting, because the solidification speed is much higher and the crystals do not have time to increase along the heat transmission preferential directions.

It follows the cooling in the secondary cooler, by spraying with water and by direct contact with the heavy guiding rollers, when occurs the solidification of the billet centre. This area consists of equiaxed and unoriented medium-sized crystals. It represents the fifth zone of solidification. Compared with the conventional casting, the fifth zone of solidification contains much less impurities, because a large part of them are decanted in the mould.

After leaving the secondary cooler, the surface temperature of billet must be about 1200^0C at the exit from the mould and $900\text{-}1100^0C$ after the secondary cooler, i.e. between the straightening / drawing rollers. The temperature of the sheared pieces is $800\text{-}850^0C$ and, when reaching the warehouse, the temperature becomes uniform throughout the section.

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In order to obtain solidification adequate to the steel chemical composition, a number of factors shall be taken into account [1, 2, 3, 11, 12], as follows:

The chemical composition of the steel *determines the drawing speed of the billet and must range within precise limits. It is required advanced silicon deoxidation, restriction of the aluminium content (Al<=0.007%, to avoid Al_2O_3 deposition on the hopper opening and its clogging) and other elements that increase the tendency to form fissures (P<0.02%, S<0.02%, As<0.03, Cu<0.3%, or P+S+As<0.065).*

The marginal crust thickness, x, *is calculated with relation:*

$$x = \frac{Q_e^{'}}{k^{'} * v_{tr} * P} \qquad (1)$$

where: Q'_e – amount of heat actually removed; k' – coefficient of proportionality; P – perimeter of the section, v_{tr} – drawing speed.

The amount of heat removed, for a given section/perimeter) is determined from the parameters of the cooling water (flow and pressure), drawing speed, lubricating film thickness and its thermal conductivity. The marginal crust must have such a thickness to not form fissures on the billet surface.

For a height of the mould of 0.6 ... 1.5 m and a drawing speed de 0.5 ... 1.2 m/min, the thickness of the marginal crust reaches 40 ... 50 mm after approx. 3 minutes.

The secondary cooling *is chosen according to the steel grade and billet section. The increase of the cooling intensity leads to the increase of compactness in the billet centre, but inner cracks can occur. The heat q removed in the secondary heater can be determined more precisely than in the mould. It can be expressed according to the heat conductivity (λ), the temperature gradient between the liquid and the solid phase (ΔT) at the solidification front, and the thickness of the crust (x,), by using the relation:*

$$q = \frac{\lambda * \Delta T}{x} \qquad (2)$$

The length of the secondary cooler, L_s, *is expressed by the relation:*

$$L_s = \frac{v_{tr} * x_1^2}{k^2} \qquad (3)$$

where: x_1 – the thickness of the crust from which the heat transfer by radiation is sufficient; k – the solidification constant.

The distance L, from the steel entrance in the mould to the place of complete solidification (after the secondary cooler) is proportional to the drawing speed:

$$L = K * v_{tr} \qquad (4)$$

where: K – constant of proportionality ($\cong$6).

The continuous casting facilities can serve any type of steel plant, but they are recommended for the steel plants with oxygen converters, which has short steelmaking process, and EAF plants working in Ultra High Power regime, in particular Supra Ultra High Power.

The section of billets must ensure a processing ratio of at least 5 ... 6, to obtain good quality rolled or forged products. It also needs to provide large cooling surfaces.

By continuous casting, slabs were produced with dimensions of up to 2100x300 for killed steel, 1300x150 for stainless steel, tiles of 50x50 in simple or composite moulds, round, hexagonal & octagonal products, profiles. No satisfactory results have been obtained for steels sensitive to cracking, or secondary oxidation, such as titanium alloy steels. In practice, it is necessary to know how the solidification of molten steel is progressing, when and where a strand is completely solidified. Just knowing the progress of solidification we can take decisions on the casting speed or cooling water flow (spraying).

The solidification of liquid steel in a continuous casting mould depends on the heat flow in the strand that transfers heat to the cooling water (which absorbs heat). This phenomenon depends on a great number of factors and varies according to the casting condition, especially the casting speed, cooling of the liquid steel and strand geometry. The heat balance in the mould is affected by the reduction in overheating, thickness of the strand crust and temperature gradient in the strand crust and along the strand surface.

The calculation of the liquid core length, for a strand cast with a given casting speed, requires information regarding the strand crust increase. The total heat transfer Q between the strand and the mould depends on the heat resistance of the solidification crust R_{Fe}, on the transition resistance from the transition surface of the strand to the cooling wall of the mould R_{FeCu}, on the resistance in the mould wall R_{Cu} and on the transition resistance of the surface between the copper wall and the cooling water R_{CuH2O}.

By considering the temperature uniformity in the strand and mould, and taking into account the solidification heat as single heat source, in the literature are shown calculation relations for the total heat flow [1, 2, 3].

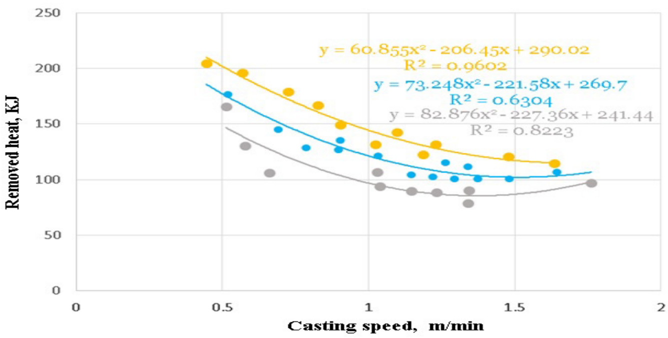

Figure 1*. The removal of heat from the mould*

The removal of heat from the mould is directly influenced by the casting speed, as shown in Figure 1. It is noted that higher casting speeds are resulting in an evenly decrease in the amount of distributed heat. This decrease is due to the fact that the rapid cast strand are in contact with the cooled wall of the mould for a short period of time and thus a lower amount of heat can be removed per unit of volume or weight of steel from a strand which is cast with a lower speed and is in contact with the mould for a longer period of time.

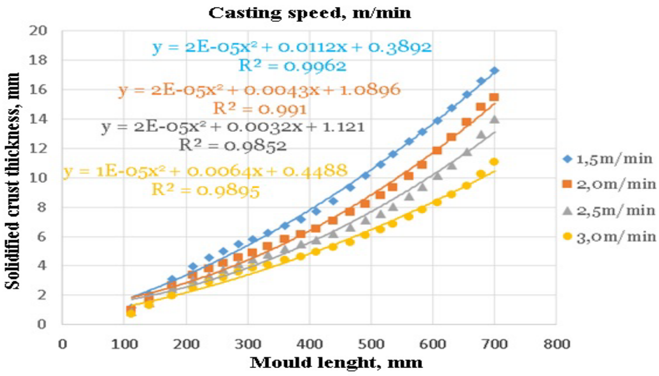

***Figure 2**. Variation of the strand crust thickness versus the mould length*

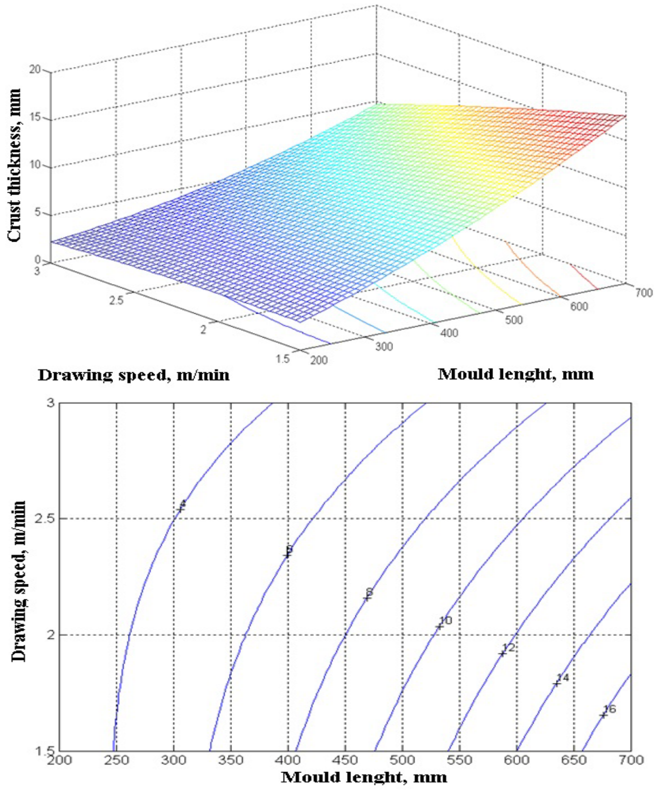

***Figure 3**. The influence of the mould length and casting speed on the billet thickness*

Figure 2 shows the variation of the strand crust thickness versus the mould length, in which there is a decrease in the thickness of the crust with the increase of the casting speed, as a result of reducing the possibility to remove a higher amount of heat.

$$Z = -0.45y^2 - 0.0096xy + 0.0283x + 3.4450y - 4.6339;$$

x – mould length, mm; y – drawing speed, m/min; z – crust thickness, mm.

Saddle point; x=62.1780; y= 3.1645; z =1.6955; $R^2 = 0.9939$

The inflection point of the correlation surface (saddle), the coordinates being located outside the technological limits.

From the analysis of data presented in Figure 3, we can see that that an increase in the mould length and casting at slower speed determine a thick crust (over 10 mm). It is very important that, at continuous casting using a given mould (i.e. a known, established length), the casting speed for a semi-finished product with known section to exceed a certain limit.

QUALITY ANALYSIS OF THE CAST BILLETS

Below we show some continuous casting defects of the billets, caused by the failure of some values of the technological parameters to range within the limits set.

***Longitudinal cracks** (Figure 4) - are formed in the direction of extraction of the steel strand from the mould, the billet presenting this type of defect being usually integrally rejected. [7, 8]*

The causes of longitudinal cracking are:

- ✓ *uneven heat removal in the mould and, as a consequence, uneven growth of the strand crust, determining transversal strains that lead to strand cracking if the crust is not strong enough (primary uneven cooling);*
- ✓ *liquid metal turbulent flow and variation of the meniscus level in the mould;*
- ✓ *secondary cooling too intense or uneven;*
- ✓ *uneven and advanced wear of the mould, which results in a different heat conductivity coefficient;*
- ✓ *high casting temperature (failure to observe ΔT);*
- ✓ *high strand extraction speed;*
- ✓ *inappropriate behaviour of the casting powder. [5, 6, 7, 8]*

***Figure 4.** Longitudinal cracks*

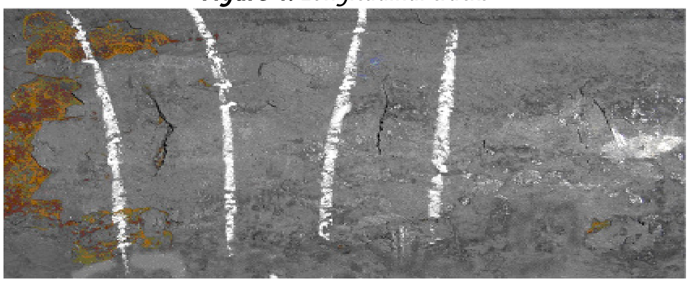

***Figure 5.** Transverse cracks*

***Transverse cracks** (Figure 5) - are rarely found in round profiles. They appear due to the strains in the longitudinal direction of the strand.*

If not deep, they are grinded (within the limits allowed by the deviations prescribed for diameter and ovality).

The causes of the transverse cracks (fissures) are:

- ✓ *heat strains due to non-uniform solidification of the crust, additional strains due to the turbulent flow below the meniscus, and variation of the meniscus level;*
- ✓ *oscillation mark depth, presence on the bottom of oscillation marks of the segregations that are cooling slower, and the austenitic grain boundaries;*
- ✓ *strain friction in the mould (at high casting speeds, the melt flow found between the mould wall and crust decreases, the marginal friction increases proportionally with the viscosity of the powder used) , or in the segments of the rolls [9, 11, 12]*

c. Stellar cracks *(Figure 6) and those caused by hot brittleness – are very fine and visible only on the scale-free surface. The surface is locally grinded for removing the defect (if it is not deep).*

Figure 6 *. Stellar cracks*

The causes of the stellar cracks are:

- ✓ *intense local cooling which induces local strains;*
- ✓ *the presence of copper at the austenitic grain boundary.[12, 13]*

Figure 7. *Internal fissures in the centre*

d. Fissures in the centre *(Figure 7) – internal fissures extended in the core, that arise due to the following causes [10, 11, 12, 13]:*

- ✓ *high casting temperature;*
- ✓ *high pressure exerted by the drawing rolls on the incompletely solidified strand.*

These defects can be remedied by observing the follows:

- ✓ *maintaining ΔT within the prescribed limits;*
- ✓ *correlating the casting speed, ΔT and cooling regime;*
- ✓ *reducing the casting speed.*

CONCLUSIONS

The continuous casting has significant metallurgical advantages compared with the classical casting method, as follows:

- ✓ *it substantially reduces the chemical and structural heterogeneity of the product due to rapid cooling (the second zone is less extensive, because the elements do not have time to segregate);*
- ✓ *the grain size is easily to control (relatively small primary grains are obtained);*
- ✓ *the non-metallic inclusions are fewer, smaller and more evenly distributed in the semi-finished product (because of the high-speed cooling, they do not have time to coagulate or agglomerate);*
- ✓ *the metal yield is higher, amounting to more than 96%, due to the fact that the shrinkage cavity is formed only once, at the end of casting;*
- ✓ *the failure to observe the set values for the casting parameters generates manufacturing defects, most of which couldn't be remedied, especially the internal ones;*
- ✓ *the semi-finished product surface is good (clean), the surface defects being mostly eliminated;*

The continuous casting has economic advantages as well, i.e.: the facilities are used more intensively, they provide a rhythmic rolling mill supply, the primary rolling mills are eliminated, the material and manpower expenses are reduced, the facilities are suitable for full mechanization and automation.

It is noted that higher casting speeds are resulting in an evenly decrease in the amount of distributed heat. This decrease can be explained by the fact that the rapid cast strands are in contact with the cooled mould wall for a short period of time and, therefore, a lower amount of heat can be removed per unit of steel volume or weight from a strand cast with a lower speed, which is more time in contact with the mould.

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