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[1.] Alina LĂSCUȚONI

STEEL THERMAL STRATIFICATION DURING STATIONARY PERIOD IN LADLE

[1.] Politechnica University Timișoara,
Faculty of Engineering of Hunedoara, ROMANIA

Abstract: *The paper presents the issue of the thermal stratification of the metal bath in the ladle during its stationary period. Due to the suggested research and experiments we aim primarily at knowing this phenomenon in detail and at investigating its influence upon the control of the temperature during the continual pouring of the steel. As a consequence of the natural convection, a vertical temperature gradient appears in the metal bath, because the metal bath, is formed of layers of steel, colder towards the bottom and the top of the ladle, and hotter in its middle section. The phenomenon of thermal stratification of the metal bath from the ladle and its influence upon the temperature control during the steel continuous casting has a major importance in steel plants.*
Keywords: *steel, thermal stratification, ladle, temperature*

1. INTRODUCTION

Because of the inevitable heat losses of the ladle, the natural convection is a phenomenon which takes place in the ladles during the stationary period, prior to its emptying. A consequence of this phenomenon is the thermal stratification of the metal bath contained by the ladle. Because of the heat loss in the liquid alloy which comes to direct contact with the refractary masonry of the ladle's walls, this cools and becomes denser than the rest of the steel. The liquid steel, colder and heavier, descends towards the bottom of the ladle, from where it pushes up the hotter and lighter steel. As a consequence of this phenomenon, a vertical temperature gradient appears in the metal bath, because the metal bath, contained by the ladle, is formed of layers of steel, colder towards the bottom and the top of the ladle, and hotter in its middle section. This phenomenon has been name „thermal stratification" in the literature.

2. SCIENTIFICAL RESEARCH

The phenomenon of thermal stratification of the metal bath from the ladle and its influence upon the temperature control during the steel continuous casting has a major importance in steel plants. This is due to the fact that the temperature of the liquid steel flowing from the furnace inside the ladle where a thermal stratification is produced will have a direct impact on the temperature of the liquid steel from the distributor of the continuous casting machine. As a consequence of this phenomenon, a temperature variation will also take place in the distributor during the pouring, as well as in the crystallizer of the continuous casting machine. The temperature variation of the steel in the crystallizer has an influence upon the structure of the pouring of blanks and upon the quality of their surface. It is obvious that the easiest technological measure for the thermal homogenization, as well as for the diminishing of the thermal stratification is sparging the liquid steel with inert gases. Due to this cause the investigation of this impact is absolutely necessary, but this firstly demands a good understanding of the phenomenon of thermal stratification inside the ladle.

According to the professional studies, we have noticed that there are only a few works related to these aspects, and the current studies have mainly focused on laboratory and industrial measurements, mathematical simulation and physical simulation.

Hlinka and Miller [1] made the first attempts in measuring the thermal stratification of the metal bath contained by a ladle, with the capacity of 7.5 to. For this, they used a bar made from refractary materials, on which they fixed three thermodevices, at different levels.

Petegnief and others [2], measured the thermal stratification from a ladle with a 7 to capacity in a similar way.

Wester [3] and Jonsson [4], in order to emphasise thermal stratification, installed three thermodevices, at different levels, in the refractary masonry of a ladle with a 7 to capacity, thermodevices which infiltrated the metal bath on a distance of 50 mm.

Rieche and others [5] and Grip [6,7], succeeded in emphasizing the thermal stratification existent in the industrial ladles, by introducing, in the metal bath of the ladle, a tool made by refractary materials equipped with thermodevices fixed at different heights.

These measurements have proven the existence of temperature gradients on the height of the metal bath and have confirmed the existence of the thermal stratification in the metal bath contained by ladles. Even more, Grip [6] has also shown that this thermal stratification can be easily prevented through the temporary shacking of the metal bath (less than 5 min), through the blasting of argon. Still, the thermal stratification appears almost immediately after the argon blasting stops, because of the fact that the ladle continually loses heat, so the natural convection takes place permanently. These results have attested that, if the metal bath contained by the ladle is „calm" (for example when the ladle is about to be emptied), the thermal stratification is inevitable as long as no other measures are taken in order to shake the metal bath.

The methods of direct measurement of the metal bath stratification contained by the ladles, previously presented, require a high discharge of effort and time, as well as high costs. Because of this, they are not recommended as strategies for the studying of thermal stratification in the ladles, however, they can still be used for checking the mathematical patterns developed with the purpose of simulating these phenomena.

Focusing on the CFD theory (Computational Fluid Dynamics), a few mathematical patterns have been developed in order to simulate the natural convection in ladles. These patterns somehow give a computational answer to the equations with partial Navier-Stokes derivatives of the turbulent pouring, equations which describe the phenomena of thermal transfer and pouring which take place during the natural convection, through the solving of whom the speed field and the temperature distribution inside the ladles result.

Ilegbbusi and Szekely [8] have developed a bidimensional pattern for the simulation of the thermal stratification phenomenon of the metal bath in a ladle equipped with an electromagnetic shaker. Their studies have emphasized the existence of the phenomenon of thermal stratification and have also shown that the thermal heterogeneity of a metal bath from a ladle can be diminished by an electromagnetic shaking of the bath.

Koo, and others [9] have also produced a CFD bidimensional pattern, used for the same purpose, with the sole difference that the shaking of the metal bath is done through the blasting of argon. Their results have shown that, for a 20 min. stationary period of the ladle, the difference in temperature between the superior and the inferior part of the metal bath can go up to even 24^{0}C, and the shaking of the metal bath by blasting argon can reduce this difference to 3^{0}C.

Austin, and others [10], has established a CFD bidimensional pattern that computes the thermal stratification of the metal bath in ladles with different capacities (125, 200 and 275 to). Focusing on the results of the research, the authors of the studies managed to correlate the speed of developing the thermal stratification with the speed of cooling the ladle on the basis of a simple linear relation, common to all the studied ladles, no matter their size.

Chakrabotry and Y.Sahai [11] have also established a CFD bidimensioanl pattern for the simulation of thermal stratification of the metal bath in the ladles, focusing on the effect that the thickness of the cinder layer from the surface of the metal bath has on this phenomenon.

3. EXPERIMENTS AND RESULTS

In order to develop these studies and to obtain some precise patterns for the stratification of the metal bath through simulation I have traced, from a thermic point of view, the process of the steel casting from the intermediate ladle with a capacity of 110 to during a period of 30-35 min/ 10 charges at ArcelorMittal Hunedoara, the O.E.2. section.

The data obtained after performing the measurements are presented in Table 1.

Table 1. The temperature of the steel during its casting from the intermediate ladle

Charge no.	Time	Temperature [˚C]
1	23:40	1554
	00:00	1555
	00:15	1548
2	22:25	1546
	22:35	1548
	22:55	1547
3	11:20	1544
	11:35	1548
	11:50	1545
4	8:05	1552
	8:20	1554
	8:40	1553
5	9:10	1552
	9:25	1555
	9:40	1553
6	2:40	1545
	2:55	1546
	3:10	1544
7	0:35	1550
	0:50	1552
	1:05	1549
8	12:15	1523
	12:30	1525
	12:45	1522
9	16:40	1537
	16:55	1540
	17:10	1536
10	3:05	1545
	3:25	1547
	3:45	1542

The thermal stratification of liquid steel can be one of the causes of the flaws in terms of material that appear during the continual pouring of the steel.

In order to avoid them one must also avoid thermal stratification, which exists in the metal bath of the ladle during its stationary period, the temperature of the liquid steel having to be as constant as possible.

The flaws in terms of material during the continual pouring of steel appear during the solidifying of the blank poured continually and its cooling, often leading to important metallic losses. [13] In order to prevent these losses, the purpose of metallurgical technologies and of the constructive purposes is to track down their causes of appearance, of prevention and of removal.

According to the professional literature, the fault can be defined as any deviation from the exterior aspect, form, dimension and macrostructure, chemical features, prescribed in standards or other active technical regulatory documents. The faults are detected at the blank reception through a visual control of the surface quality on the inspection bases or during the control of the sample macrostructures in the laboratory.

A fault is not always the consequence of a unique cause. Many times the fault is the result of the interaction between more than one cause, depending on a fluctuant number of parameters.

Similar faults, as far as the exterior aspect is concerned, can have one or more different causes, as well as apparently different faults can have, in between causes, one or more common causes. That is why, we can often observe the existence of more faults on the same blank. The faults that appear during the continual pouring of the steel can be classified as follows: surface faults, internal faults, shape faults, mechanical faults and deviations from the chemical composition of steel.

Let us now remember some of the faults in terms of material that appear during the continual pouring of the steel caused by defying the pouring temperature according to the limits estimated by technology.

4. SURFACE FAULTS

a) Fissures

Longitudinal fissures *(figure 1) – are formed in the direction of extraction of the wire in the crystallizer, the bar that displays this fault usually being discarded totally.*

The causes that lead to the appearance of the longitudinal fissures are:

- ✓ *the irregular removal of the heat in the crystallizer and, consequently, the irregular growth of crust on the wire, thus causing transversal fissures which lead to the breaking of the wire, if the crust is not strong enough (primary irregular cooling);*
- ✓ *the turbulent fault of metal and a variation in the level of the meniscus in the crystallizer;*
- ✓ *the too intense or irregular secondary cooling;*

- the unequal and advanced wearing of the crystallizer which results in a different coefficient of thermic conductibility;
- a high casting temperature (defying ΔT);
- the high speed of wire extraction;
- the abnormal behavior of the pouring dust.

Figure 1. Longitudinal fissures

Stellar fissures (Figure 2) and the ones determined by the fragility to heat – are very smooth and visible only on the surface without dross. They are polished locally in order to remove the fault (in case it is not deep).

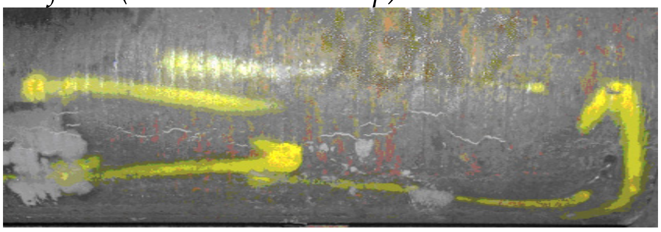

Figure 2. Stellar cracks

The causes that lead to the appearance of stellar fissures are:

- the intense local cooling that induces local tensions;
- the presence of copper at the limit of the austenitic grain.

b) Depressions

Longitudinal depressions (Figure 3) – appear because of:

- the uneven thermal transfer in the crystallizer tank which determines the unequal expansion of the marginal peel;
- the oscillation of the steel level in the crystallizer tank as well as a way larger quantity of melted flux between the wall of the crystallizer tank and the wire;
- the turbulent flow of the steel in the sub-meniscus;
- the unequal and advanced depreciation of the crystallizer tank which has as consequence a different coefficient of thermal conductibility.

c) Casting disruption

Casting disruption (Figure 4) – is determined by a short disruption of the casting process, and the fault is scavenged through shaking the bar that contains it. This fault appears because of the sudden variation of the casting speed which is due either to the temperature variation of the steel from the distributor, either to the level variation from the crystallizer tank, either to the casting method (manually).

The main way of remedying the problem is maintaining a constant casting speed by assuring a low level of thermal variation in the distributor, by maintaining the level from the crystallizer tank within the given limits and by using an automatic method of casting.

Figure 3. Longitudinal depressions

Figure 4. Pouring disruption

d) Cavity

Cavities (Figure 5) – represent an empty space in the material, visible in the transversal section, at the end of a bar and it is scavenged by cutting off the end of the bar, and the flawed portion is discarded. This fault may be caused by:

- a high casting temperature;
- a high extraction speed;
- intense after cooling.

Figure 5. Cavity

5. INTERNAL FAULTS

a) Fissures

Are openings in the interior of a slab billet, identified by macroscopic analysis and can be:

Internal marginal fissure (Figure 6) – is short and very close to the surface tears, under the dingle and can be caused by:

- ✓ a high casting temperature;
- ✓ a high casting speed;
- ✓ intense after cooling and jet cooling;
- ✓ uneven distribution of the lubrication powder between the crystallizer tank and the rack.

Figure 6. Internal marginal fissures

Central fissure (Figure 7) – internal fissures that extent to the core and which appear due to the following:

- ✓ a high casting temperature;
- ✓ a high pressure of the pulling cylinders on the incompletely solidified wire.

Figure 7. Central fissures

b) Micro cavity

Micro cavity (Figure 8) – is a lack of material in the central part of a transversal section (sample), taken from a steel bar. It appears after a contraction of the material in the process of turning from a liquid state in a solid state.

This fault appears because of:

- ✓ a high casting temperature;
- ✓ a high extraction speed;
- ✓ an intense after cooling;
- ✓ the maintain of the ΔT in the given limits;
- ✓ the correlation of the casting speed, ΔT and a cooling system;
- ✓ reducing the casting speed;
- ✓ reducing the cooling intensity by maintaining the water debit at the given minimum level.

Figure 8. Micro cavity

c) Central pinches

Central pinches (Figure 9) – are a lack of interior homogeneity of the continuous casting wire and can be sometimes accompanied by a cavity, having the same causes for the apparition. During the ulterior heating it is soldered together and the continuous casting material should not be discarded.

Figure 9. Central pinches

Causes for the apparition of central pinches are:

- ✓ a high casting temperature;
- ✓ a high extracting speed;
- ✓ intense after cooling.

6. CONCLUSIONS

Because the thermal stratification, existent in the metal bath of the ladle in its stationary period, (before its descent), must be as low as possible and have a somehow constant temperature, the following ***technological measures*** *must be applied:*

- ✓ *The stationary period should be as small as possible;*
- ✓ *The initial thermal content of the ladle, (valued by the temperature of the interior surface of the clay work, before filling it up with liquid alloy) must be as high as possible;*
- ✓ *The clay work of the ladle must be made from materials with a very low thermal conductibility;*
- ✓ *The layer of slag, from the surface of the metal bath, must have a thickness of 60-70 mm;*
- ✓ *The descent debit of the ladle must have the highest value, dependent on the casting speed;*
- ✓ *Before casting in the distributor, argon splashing is obligatory;*
- ✓ *Establishing some precise correlations between the technological parameters of casting (the casting speed, the pulling speed and the cooling speed) and the temperature of the steel from the distributor / crystallizer tank;*
- ✓ *The smallest possible amount of response time to the modification of the parameters.*

We consider the simulation program Autodesk Algor Simulation Professional 2010 for the study of heating transfer can offer relevant information about the phenomena that take place during the steel continuous casting, without high costs and a low degree of time and effort.

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