CONTINUOUS CASTING FOCUSED IN TUNDISH METALLURGY: A CRITICAL LOOK ABOUT PROCESS PARAMETERS REGARDING STEEL CLEANLINESS*

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Abstract

The continuous casting machine is one of the most important steel production steps in a melt shop. The tundish, a reservoir between the steelmaking ladle and the mold, has great influence over the steel cleanliness, along with the productivity bid. It must takes into account the quality of the metal and operational safety. Several different variables are related to the tundish process, of inclusionary cleanliness. Some of them are discussed in this paper: the free opening of ladle, tundish inertization, steel temperature in the reservoir and clogging formation, besides a brief topic about castability. Therefore, a critical analysis, with a review from some papers available in literature, is proposed in this study, with its focus on tundish.

Keywords: Continuous casting; Tundish; Process variables; Clean steel.

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1 INTRODUCTION

The steel production with Continuous Casting (CC) is widely spread all over the world. Approximately 90% of the produced steel is conducted through this process [1]. In some parts of the globe CC represents around 95% of the metal production. Simultaneously with this production increase there are the strict quality requirements that become very important when taking into consideration the progressive increase on the machine productivity.

Quality requirements are often related to inclusion formation in steel. Inclusions can be divided according to their origin [2, 3]. They can be classified as indigenous or exogenous. Indigenous are created as reaction products of deoxidation reaction during the steel production process. While the exogenous are inclusions originated from chemical or mechanical interactions unwanted from liquid metal with refractories, slag or atmosphere [4].

According to Costa e Silva [5], related to the formation of inclusions, two important factors must be considered: nucleation and inclusion morphology. There is a fast nucleation process, with the addition of a deoxidizing element. The higher the oxygen content dissolved in steel, the higher the quantity of oxides created by the reaction with the deoxidizing element. When chemical composition matters, inclusions can be classified as sulfides, nitrides and phosphides. The oxides include alumina inclusions, sílica, calcium aluminates, spinels, aluminium and manganese silicates, iron and manganese oxides, among other mixed oxides. Size distribution of the inclusions is also very important [6]. The number of inclusions depends directly on the oxygen content of the steel.

The demand for cleaner steel increases every year. Besides decreasing the concentration of non-metallic inclusions, the tundish (TD) has essential importance in steel quality. The TD is the last metallurgical reactor where metal flows before solidification in mold. During the transfer of the steel into the reservoir, the metal interacts with lining refractories, slag and atmosphere. Therefore, design and appropriate operation of the apparatus are important to establish steel in the right composition and adequate temperature. Figure 1 describes the variables, related to inclusion removal process (in tundish) discussed in this paper.

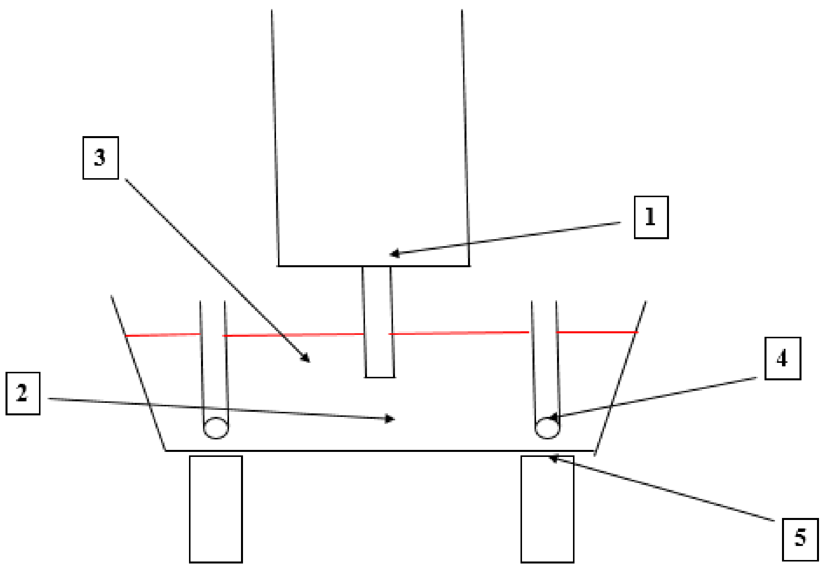

Figure 1. Process variables analyzed in this paper: 1 - free opening of ladle; 2 - tundish inertization; 3 - steel temperature; 4 - clogging; 5 - castability.

The scheme shows the free opening of ladle as being the first parameter to be discussed, followed by tundish inertization, steel temperature in the resevoir, the formation of clogging and castability.

According to the literature review, Ohno et al. [7], concluded that reoxidation, a problem related to inclusionary cleanliness, increased macroinclusions quantity by a factor of 2.5 between ladle and tundish. Regarding steel flow, there is the promotion on the uniformity of distribution and removal of inclusions, avoiding at the same time, surface turbulences, dead zones and vortex formation. The flow in TD must carry the inclusions to the steel surface and take them throughout the covering with a low level of turbulence, allowing these impurities to rise to the slag, avoiding emulsification and slag entrapment.

The process reviews aiming at the operational problems diagnosis, their development and optimization, require the use of mathematical and/or physical models of the related processes.

In the theory of mathematical modelling of fluid dynamics, the use of a mathematic CFD (Computational Fluid Dynamics) tool was at the beginning directed as a way of evaluating physical problems and in some cases was employed in computer science to simulate fluid flow [8].

Inclusions, that are traditionally only found in trace quantities, are becoming a growing problem due to their accumulation. These elements cause intergranular segregation causing the appearence of cracks and other problems, that are usually manifested as failures in the final product. These elements can also be hard to remove in steel refining [9].

Critical cleanliness problems in final products are mostly associated with macro inclusions (clusters of fine inclusions, reoxidation products, slag or refractory entrainments) but increasingly, stringent requirements and the need to prevent nozzle clogging also demand reductions in smaller-sized inclusions [10].

Therefore, after an introduction about the steel cleanliness in the continuous casting, a critical look about some variables, that are responsible for rising of macroinclusions in steel production, was carried out in this paper. The influence of free opening performance of steel ladle, inertization, temperature of steel in tundish, stopper rod level variation (clogging formation) along with a brief review about castability, concerning internal quality of the material, are described.

2 DEVELOPMENT

In this item, the following variables: free opening of steel ladle, inert gas use in tundish, steel temperature, clogging formation and castability are reviewed according to their sequence in steel production process of continuous casting.

2.1 Free opening of steel ladle

The moment of ladle opening in CC is very important to the continuation of the process. Any failure in the free flux of steel causes loss of sincronism, that can vary from a simple delay on the production until the complete stop of the casting machine, along with the security risks involved [11].

Among several factors known as causes for the non-opening of ladles, there are the mistakes and inaccuracies in the sealing operation of the slide gate with the use of granular material.

In order to avoid contact between liquid steel and the slide gate system, a refractory material is used in the opening of ladle. This material is called filler sand [12]. DIfferent types of sand can be employed. Sands with chromite are widely used. There are many operational variables and features that affect the material performance [13].

Some of the most important properties of the filler sand are: refractoriness, grain size distribution, packing density, creep and besides all that the capacity of forming a sintered crust with appropriate thickness when in contact with the metal [14].

In Carvalho et al. [15], a computational simulation was carried out to simulate the heat losses, that could affect the steel cleanliness. The filler sand, if incorporated to the material, somehow, could be a site for the nucleation of indigenous inclusions (Figure 2), and aggregate the impurities of different chemical compositions.

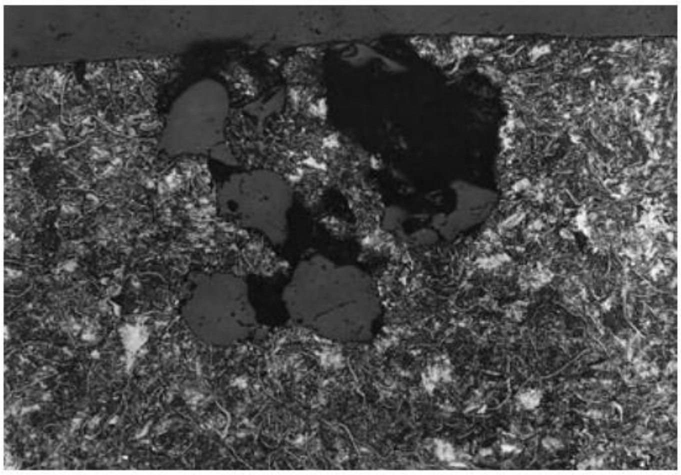

Figure 2. Micrograph of an inclusion defect in a grey iron cast. The embedded sand grains are clearly recognizable [16].

Figure 2 shows a sand inclusion, that is one of the most frequent causes of casting rejection. It is often dificult to diagnose, as these defects generally occur at widely varying positions and are therefore very difficult to atribute to a local cause [16].

2.2 The use of inert gas in tundish

Despite the costs involved in production and maintenance of the covers and tundishes and due to the lack of visualization on surface by operators, the use of lids indicate several advantages, such as the possibility of pre-inertization through argon injection, to prevent steel reoxidation by atmospheric air. There is also the possibility of the tundish pre-heating, aiming at the decrease of water content in the refractories. Since moisture can cause reactions with the bath in the beginning of the sequence, hidrogen pickup or cause the formation of inclusions when in contact with deoxidizing agents [10].

In a steelmaking plant from South Korea, for instance, some experiments were carried out, in the reduction of oxygen in steel and nitrogen content through pre-inertization of the sealed tundish. The process of the first heat in this procedure was the following: 60 ton tundish pre-heating, beginning of argon injection, adjustment of the TD on the continuous casting position, ladle opening, filling of the equipment and the end of the argon injection (where less than 1% of the oxygen still remains in the resevoir atmosphere) and finally the start of the machine. A significant reduction was observed in total oxygen and nitrogen in steel, along with the inclusionary cleanliness, as demonstrated in Figure 3 [17].

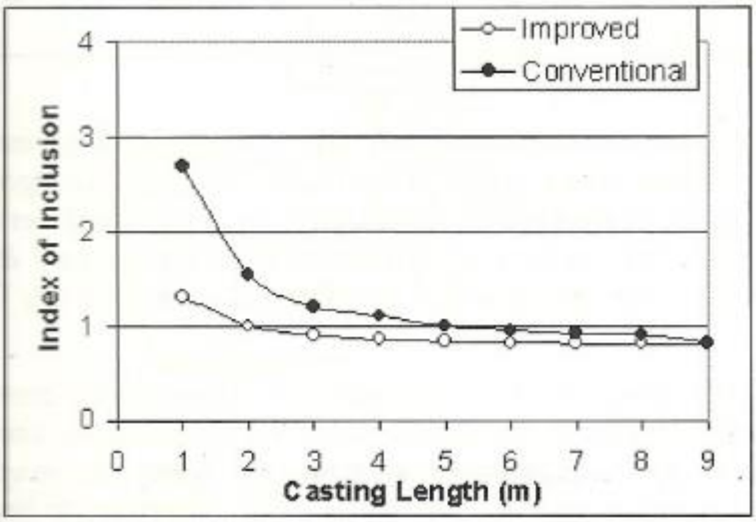

Figure 3. Inclusionary cleanliness, with use of conventional and pre-inertized (improved) tundish.

The graphic from Figure 3 shows the efficiency on the use of injection of inert gas in the tundish versus the inclusion index.

2.3 The temperature of steel in the TD

Controlling the steel temperature is very important for an efficient and stable production [18]. For example, surface cracks can occur, the product quality can be deteriorated or a breakout can be originated in a worst case, if liquid steel temperature is not precisely controled in the continuous casting process.

High temperatures in tundish cause modifications in the formed structure during solidification, making possible an increase in the columnar zone and reduction in the equiaxial zone, causing segregations, porosities and cracks. These high temperatures also speed up the reaction kinetic with refractory materials increasing their wear and making it harder to clean the steel [19].

On the other hand low temperatures can cause the increase of the slag viscosity, making it hard for the inclusions to flotate and also being harmful to steel cleanliness. Furthermore, an increase in the deposition of inclusions in the stopper rod, being possible to cause the steel contamination with macroinclusions due to the clogging on the rod, is possible.

2.4 Clogging formation

The steel flux from tundish to mold can be done by the use of two ways of control, the slide gate and the stopper rod. In both it is usual the accumulation of inclusions in the bottleneck flux region. It causes the leakage interruption or difficulties in maintaining the cast speed [20, 21].

The speed and stopper rod position indicate clogging, the obstruction on the tundish exit towards the strand. But they cannot answer the question about how much time the continuous casting can continue and when the rod must be changed [22].

The clogging can be removed "punching" the stopper rod with a sudden movement of the refractory in the direction of the submerged entry nozzle (SEN) connection, giving sequence to the continuous casting without changing the nozzle. One disadvantage is the material that is pulled into the mold is contaminated with impurities.

Several authors are trying to understand the mechanisms that cause this phenomenon of clogging. Singh [23] carried out studies in a pilot plant, using steel with high quantity of inclusions to amplify clogging occurrence. He observed the inclusions placed close to the limit layer had lower velocity and then they have the tendency of getting stucked on the walls of the stopper rod.

Wilson et al. [24], conducted tests in pilot plant and through computational numerical modelling to characterize the flow around the rod region. One finding was that for inclusions with diameter above a determined value, close to 35 µm, the main mechanism that make the inclusions migrate to the rod wall is the centripetal force that interfere on them in the region where this bottleneck occurs. For inclusions with diameter lower than 35 µm, the main cause of deposition would be the turbulence that occurs due to the bottleneck.

Bielefeldt [25] and Bannenberg [26] explain the term obstruction of the nozzles is related to the alumina accumulation or high content of alumina, constricting the flux of the submerged nozzle. Two regions are considered the most affected: the area above the submerged entry nozzle and the zone the steel gets out towards the mold.

This accumulation of impurities makes the steel dirty, hence having an increase in the inclusions number.

2.5 Castability

The definition for castability depends on the type of metal and process [27]. For continuous casting processes, castability is related to metal flow and clogging formation tendency [28].

The phases present in the inclusions in equilibrium with a specific temperature can be estimated through calcium vs. aluminium phase diagrams, where the liquid phase defines the region called liquid window [29].

Several factors have influence on steel castability: refractory materials, slag composition, tundish covers, the SEN material and design, temperature control, tap-to-taps, etc. The inclusions control is only one of the factors. However, it is very important on trying to improve the steel capacity of casting well [25, 30].

In Figure 4 the results for a total oxygen content of 10, 20 and 40 ppm, combined with a 250 ppm sulfur level are demonstrated.

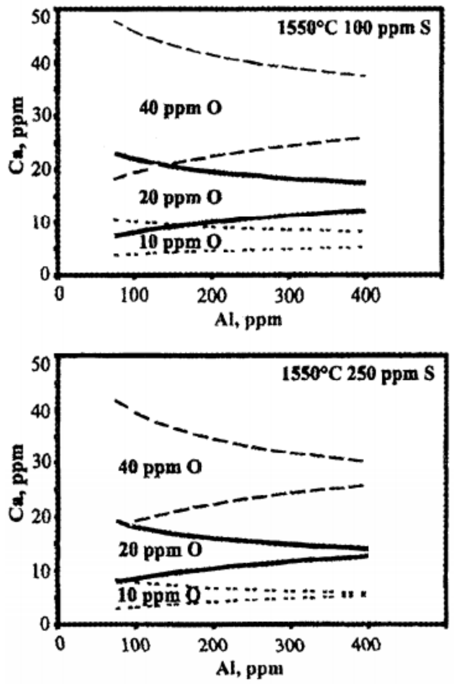

Figure 4. Total Oxygen effect over 100 or 250 ppm of Sulfur liquid window.
Source: Holappa et al. [31].

When oxygen content is low, the liquid window is obtained with a low calcium level, besides being narrow. When the oxygen content increases, calcium addition also increases and the window gets broader. Sulfur effect can be noted in the saturation lines of CaS: a high sulfur content makes the window more narrow.

3 CONCLUSIONS

After the review carried out in this work it could be concluded that the free opening of the steel ladle is crucial for the metal production as well as the quality of the liquid steel. The filler sand, placed over the shroud and the slide gate system, must originate a sintered crust with appropriate thickness when in contact with the metal and, if incorporated in steel, can play a role in the nucleation of inclusions.

Furthermore, the tundish gets better cleanliness when is inertized, comparing to the non-use of argon, usually in first of sequence and less than 1% of oxygen remains in the resevoir after this procedure. Regarding temperature, when it is high, segregations, porosities and cracks can be raised. While low temperartures cause an increase in slag viscosity, being harder for the inclusions to flotate.

When the stopper rod is taken into account, clogging must be avoided and through this research, one finding was that for inclusions with diameter above a determined value (35 µm) the main mechanism that make the inclusions migrate to the rod wall is the centripetal force, while for inclusions with diameter lower than 35 µm, the first cause of deposition would be the turbulence that occurs due to the bottleneck originated.

Therefore, these studied variables can be considered some of the main ones in the continuous casting process, focused in the tundish, because they have direct influence in the inclusionary cleanliness and also in internal quality of the steel.

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REFERENCES

1 SAHAI, Y; EMI, T. Tundish technology for clean steel production. 2008.
2 GHOSH, A. Secondary steelmaking: principles and applications. CRC Press. P. 322. 2001.
3 MORAES, LAB. Caracterização de macro e micro-inclusões em aços acalmados ao alumínio produzidos por lingotamento contínuo. Master dissertation. São Paulo University. São Paulo. 2009.
4 FINARDI, J. Inclusões em aço: seu efeito e seu controle. *Congresso de Engenharia Metalúrgica da Universidade Mackenzie*. São Paulo. 1989.
5 COSTA E SILVA, ALV. Non-metallic inclusions in steels - origin and control. Journal of Materials Research and Technology. V. 7. P. 203-402. 2018.
6 BIELEFELDT, WV. Estudo do tratamento de inclusões com cálcio na fabricação do aço SAE 8620. Master dissertation. Federal University of Rio Grande do Sul. Porto Alegre. 2005.
7 OHNO, T; OHASHI H, MATSUNAGA. ISIJ, 1975.
8 BLAZEK, J. Computational fluid dynamics: principles and aplications. Elsevier, 2001.
9 ZHANG, L; THOMAS, B. State of the art in the evaluation and control of steel cleanliness. ISIJ International. P. 271-291. V. 43. 2003.
10 WUNNENBERG, K; MILLMAN, S; NADIF, M; MARIQUE, C; SUMIDA, M; WEDDIGE, J. ISII Study on Clean Steel. International Iron and Steel Institute. 2004.
11 LAVINAS, A; VRONEZE, R; PEREIRA, O. LOPES, JÁ; VALADARES, CAG. Mecanização personalizada do método de adição de areia refratária às panelas de aço em aciaria. ABM Week. São Paulo. 2018.
12 CRUZ, RT; PELISSER, GF; BIELEFELDT, WV; BRAGANÇA, SR. Free opening performance of steel ladle as a function of filler sand properties. Materials Research. V. 19 (2). P. 408-412. 2016.
13 TOMBA, AG; CAMERUCCI, MA; CAVALIERI, AL. Ladle filler sand evaluation. Proceedings of the Unified International Technical Conference on Refractories. Orlando. 2005.
14 TSENG, TT; WU, HM; CHEN, CN; UAN, JY; WU, W. Refractory filler sands with core-shell composite structure for the tap hole nozzle in slide-gate system of steel ladles. Ceramics International. P. 967-971. 2012.
15 CARVALHO, MC; OLIVEIRA, DR; RUSKY, GC; PINHEIRO, BC; SOUZA, JAS; BRAGA, EM. Simulação computacional das panelas de aciaria da siderúrgica Sinobras. TMM. P. 138-145. V. 11. São Paulo. 2014.

16 Description of defects: sand inclusions. foundrygate.com. Accessed in 06.30.2019

17 FERREIRA, FB. Análise e verificação de variáveis do processo como causas para o sucateamento por macroinclusões em uma aciaria de aços especiais. Final Report. Federal University of Rio Grande do Sul. Porto Alegre. 2011.

18 SAKASHITA, S; OKURA, T, AHMAD, I; KITADA, H; MURATA, N. Gray-box model to control molten steel temperature in tundish. IFAC Proceedings Volumes. V. 45. P. 268-269. 2012.

19 FERREIRA, NF. Controle da temperatura do aço líquido em uma aciaria elétrica. PhD Thesis. Federal University of Rio Grande do Sul. Porto Alegre. 2000.

20 RACKERS, KG; THOMAS, BG. Clogging in continuous casting nozzles. 78 th Steelmaking Conference Proceedings. Iron and Steel Society. V. 8. P. 723-734. 1995.

21 BAI, H; THOMAS, BG. Effects of clogging, argon injection and casting conditions on flow rate and air aspiration in submerged entry nozzle. Steelmaking Conference Proceeding. P. 1983-97. Pittsburg, USA. 2000.

22 IKÄHEIMONEN, J; LEIVISKÄ, K; RUUSKA, J; MATKALA, J. Nozzle clogging prediction in continuous casting of steel. IFAC Publications. 2002.

23 SINGH, SN. Mechanism of alumina buildup in tundish nozzles during continuous casting of aluminum-killed steels. Metallurgical Transactions. V. 5. 1974.

24 WILSON, FG; HEEMSON, MJ; NICHOLSON, A; HILLS, AWD. Effect of fluid flow characteristics on nozzles blockage in aluminum-killed steels. Ironmaking and Steelmaking. V. 14. 1987.

25 BIELEFELDT, WV. Tratamento de inclusões não-metálicas com cálcio nos aços SAE 1141 e SAE 8620. PhD Thesis. Federal University of Rio Grande do Sul. Porto Alegre. 2009.

26 BANNENBERG, N. Inclusion modification to prevent nozzle clogging. Steelmaking Conference Proceedings. P. 457-463. Nashville, USA. 1995.

27 JÚNIOR, VGS. Verificação do efeito de injeção de gás através de válvulas submersas multiporos sobre a lingotabilidade e limpeza do aço. Master dissertation. Federal University of Rio Grande do Sul. Porto Alegre. 2009.

28 JANKE, D. Improvement of castability and quality of continuously cast steel. ISIJ International. V. 40. P. 31-39. 2000.

29 LINO, RE; MARINS, AMF; MARCHI, LA; MENDES, JA; PENNA, LV; NETO, JGC; CALDEIRA, JHP; COSTA E SILVA, ALV. Influência da composição química na lingotabilidade dos aços. 69 º Congresso Anual ABM. São Paulo. 2014.

30 HOLAPPA, L. Inclusion control for castability of resulphurized steels. Proceeding of 60 the Ironmaking Conference. P. 1023-1035. Baltimore, USA. 2001.

31 HOLAPPA, L; HAMALAINEN, M; LUIKKONEN, M; LIND, M. Thermodynamic examination on inclusion modification and precipitation from calcium treatment to solidified steel. Ironmaking and Steelmaking. V. 30. P. 111-115. 2003.