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The influence of tundish heating and purging on inclusion formation

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Abstract

Steel with high cleanliness requirements require an accurate control of the non-metallic inclusions, such as its quantity, morphology, chemical composition and size distribution. The continuous casting tundish has a fundamental role in steel cleanliness, avoiding its reoxidation by air and ladle slag that retain inclusions, as well as aiding the removal of those same inclusions along the continuous casting (Sahai, 2008). To perform the study, IF steel samples were collected in RH at the start, in the middle and at the end of the continuous casting of the tundish's first heat in three different conditions of tundish processing, alternating between heating and purging. These samples had their inclusions characterized by MEV/EDS using the ASCAT (Automated Steel Cleanliness Analysis Tool) technology. The results showed that more than 90% of the oxide inclusions generated in that type of steel are Al_2O_3 and AlTi. It was also observed that there is an increase of steel inclusions originating from RH in the tundish and that area fraction and average inclusionary density decreases along the continuous casting in two of the processing conditions.

Keywords: Inclusions, tundish, ASCAT and purging.

1. Introduction

The requirements for steel mechanical properties and chemical composition are in constant transformation with the growing demands for quality; at the same time, the cost, energy and environmental effect in production have also become items of great concern. Hence, steel properties such as mechanical resistance, malleability, durability and resistance to corrosion have improved over the years to meet such needs. This was achieved partly by producing the so-called "clean steel", or steels of high cleanliness in relation to the presence of non-metallic inclusions deteriorate most of the mentioned properties Zang and Thomas, (2002) and Choudhary, (2011).

An experiment was developed on an industrial scale at ArcelorMittal Tubarão Steel Company, using the actual productive process of Continuous Casting, where the focus was on the evolution and generation of inclusions in the Continuous Casting tundish. The experiment result supplies a quantitative and qualitative description of inclusions generated in the tundish's first heating, and under defined and controlled conditions of heating and previous purging of that same tundish .

The present work aims to evaluate the cleanliness of an ultra low carbon IF (Interticial Free) steel produced in Continuous Casting, through the analysis of Al_2O_3 and AlTi inclusions generated in three different tundish processing conditions: a) with heating and purging of inert gas b) with heating and no purging and c) with no heating and with purging. Steel samples were collected in RH and at the start, in the middle and end of the tundish's first heating of the casting. These samples had their inclusions characterized by SEM/EDS using ASCAT (Automated Steel Cleanliness Analysis Tool) technology.

2. Materials and methods

Three different types of Ultra Lower Carbon steel - IF processing were studied in the continuous casting tundish:

a) Tundish with Hot Start and with preliminary Purging (AP);

b) Tundish with Hot Start and No preliminary Purging (ASP) and

c) Tundish with Cold Start and with preliminary Purging (FP). Figure 1 corresponds to the schematic drawing of the Ultra Lower Carbon steel processing runs in the tundish sequence, showing the sample collection points for the steel cleanliness study of the first heat of the tundish.

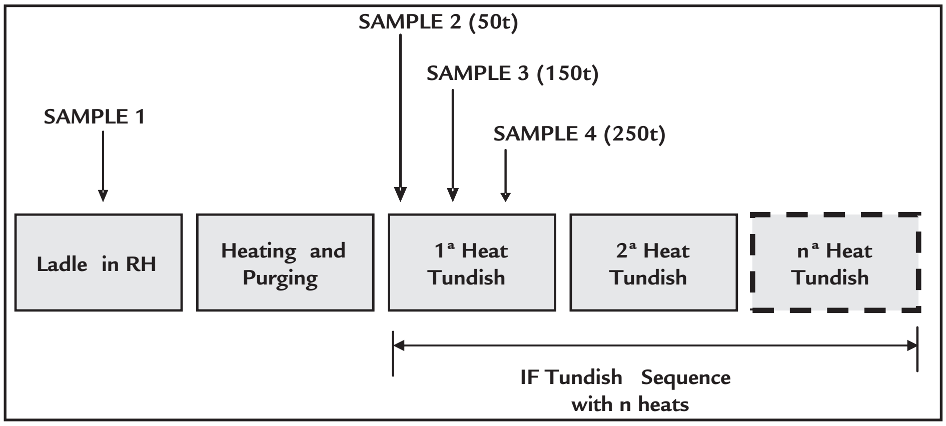


Figure 1
Sample collection in the pot and tundish.

The following information summarizes the stages that were followed for the development of this work.

'Lollipop' type samples of Ultra Low Carbon steel were collected in the tundish sequence's first heat of the Continuous Casting in the three different processing conditions described below, equally in the RH ladle as in the Tundish;.

The samples were sent to the ArcelorMittal research center in Chicago-USA for inclusion characterization via sweeping electronic microscope SEM / EDS using ASCAT technology (RJ Lee Group, 2005);

From the data, the steel cleanliness results were analyzed in the RH and tundish (Al_2O_3 and AlTi inclusions) individually for each processing condition as well as by comparative analysis among the different processes.

Experiment samples were removed in three different heats for each type of processing in the tundish, as shown in Table 1, being that in each situation, a ladle sample after RH treatment and three samples of the same heating were removed during its casting in the tundish, making a sub-total of 12 samples for each experiment, and a total of 36 final samples. The sampling stages are:

i) one sample in the ladle after treatment in RH and liberation for Casting. This sample aims to characterize the inclusion that is getting into the continuous casting.

ii) Three samples in the first heat of the tundish during its casting from the ladle mentioned in item i. The first sample will be removed after having drained 50t from the ladle, practically after filling the tundish up, the second one after having drained 150t from the ladle, practically a half of the ladle and the third sample leaving 50t for the end of the ladle. It is important to note that the experiment is only focused on the tundish's first heating, as it is the one with the biggest influences from the preliminary procedures of tundish heating and pre-purging.

Sampling condition	Heat 1	Heat 2	Heat 3
Tundish with heating and purging (AP)			
Collected in RH ladle	AP1	AP2	AP3
Collected after 50t casted into tundish	AP50.1	AP50.2	AP50.3
Collected after 150t casted into tundish	AP150.1	AP150.2	AP150.3
Collected after 250t casted into tundish	AP250.1	AP250.2	AP250.3
Tundish with heating and no purging(ASP)			
Collected in RH ladle	ASP1	ASP2	ASP3
Collected after 50t casted into tundish	ASP50.1	ASP50.2	ASP50.3
Collected after 150t casted into tundish	ASP150.1	ASP150.2	ASP150.3
Collected after 250t casted into tundish	ASP250.1	ASP250.2	ASP250.3
Tundish with no heating and purging (FP)			
Collected in RH ladle	FP1	FP2	FP3
Collected after 50t casted into tundish	FP50.1	FP50.2	FP50.3
Collected after 150t casted into tundish	FP150.1	FP150.2	FP150.3
Collected after 250t casted into tundish	FP250.1	FP250.2	FP250.3
Total of samples	36		

Table 1
Samples collected in the study.

For a reproductive guarantee of the different trial process heats, some basic operational variables of the continuous casting process were maintained in constant range: casting temperature, casting speed, covering powder quantity, heat casting time and ladle opening without use of oxygen.

Of the inclusion indicators supplied by ASCAT, two figure among the more used and representative for cleanliness measurement in this work. The first is *inclusion Area Fraction* (Area occupied by an inclusion class in μm² / total analyzed Area in mm²) and the second is *Inclusion Density* (numeric amount of certain class of inclusions / total analyzed Area). The occupied Area Fraction notably stands out in cleanliness evaluation for considering not only the quantity, but the inclusion sizes, representing the density of impurities in the steel. Although the number of large inclusions is much smaller than those of minor inclusions, its volumetric fraction can be larger, and a simple inclusion of great size found in the material can cause relevant defects. Also inclusion size distribution was evaluated.

3. Results and discussions

Firstly, it was checked and confirmed that all the assisted runs met the process variables described in the previous chapter; there was no need to discard any sample.

The Figure 2 shows the average Area Fraction of several oxide classes observed in the samples collected in RH and in the three distinct conditions in the Continuous Casting processing.

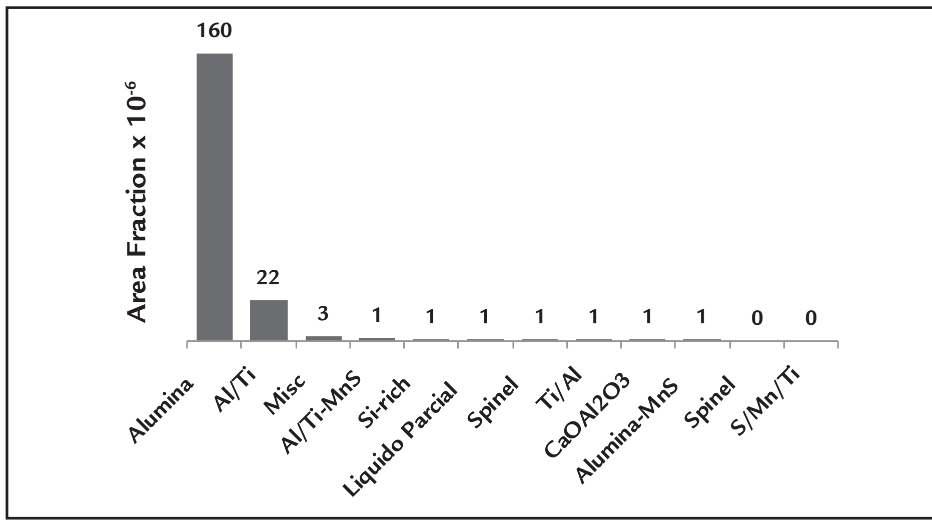


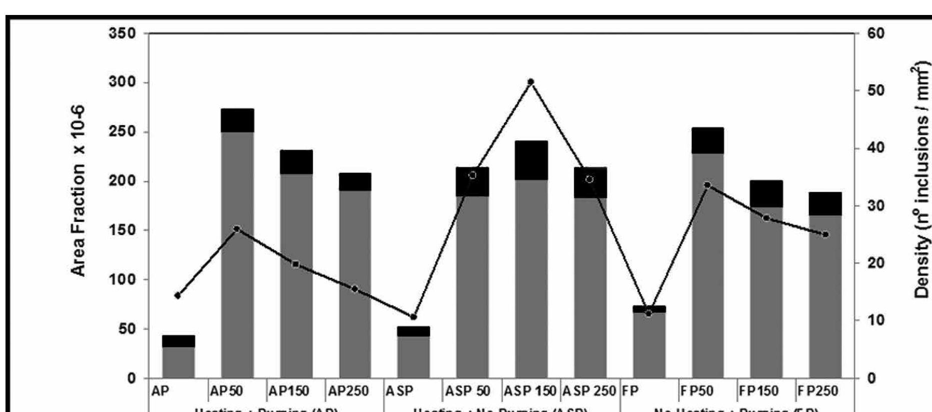
Figure 2
Area fraction average of inclusions found by ASCAT in the different studied process.

The two majority inclusion groups presented in the samples and the focus of this work were Al_2O_3 and AlTi inclusions; Al_2O_3 inclusions occupied proportionally seven times more area than AlTi inclusions. MATSUURA *et al* (2007) shows that the generation of less AlTi is due to the fact that the titanium, used as element stabilizer, is only added to the steel at the end of RH treatment and in small amounts, while alumina is generated from the intentional aluminum oxidation for steel deoxidation.

The average result of 4 sample groups collected in three different run for each type of tundish processing is shown as follows.

Comparative Evaluation of Al_2O_3 and AlTi Inclusions in the Three Processing Types

The Figure 3 presents the average Area Fraction and average inclusionary Density of Al_2O_3 and AlTi Inclusions together in the three studied processes.



	AP	AP50	AP150	AP250	ASP	ASP 50	ASP 150	ASP 250	FP	FP50	FP150	FP250
AlTi	12	23	24	18	10	29	39	32	6	26	26	23
Al2O3	32	250	208	191	43	184	202	183	67	228	174	165
Density total	14	26	20	15	11	35	51	34	11	33	28	25

Figure 3
Area fraction and density average of Al_2O_3 e AlTi inclusions in the three different studied process.

It is seen that the smallest occupied Area Fraction by AlTi inclusions in the three cases, which on average are 6 times smaller than the occupied Area fraction for Al_2O_3 inclusions, as already shown in the Figure 2. as well as the total Area Fraction, the inclusionary Density total plotted in the secondary axis of the same graph show similar evolution in the three processes, with the increase of RH inclusion totals (samples AP, ASP and FP) for the Tundish (AP50, ASP50 and FP50 samples). According to Tanaka *et al*. (1993) that behavior is explained due to the first steel portion that enters in the tundish being totally unprotected, entering in contact with the air and forming new Al_2O_3 exogen inclusions and worsening the steel cleanliness.

Inclusionary reduction of the two cleanliness indicators is also observed in the graph during the casting in the three evaluated processes, in other words, the tundish's initial samples (AP50, ASP50 and FP50 samples) until the last ones (AP250, ASP250 and FP250 samples). This reduction along the casting is expected and according to Sahai and Emi (2008) due to the tundish's steel renewal coming from the ladle and greater cleanliness, and as a secondary cause the tundish's own capacity to remove inclusions by flotation as the steel passes through it towards the mold.

The analysis of Figure 4 together with Table 2 shows the following tendencies in relation to the three studied processes:

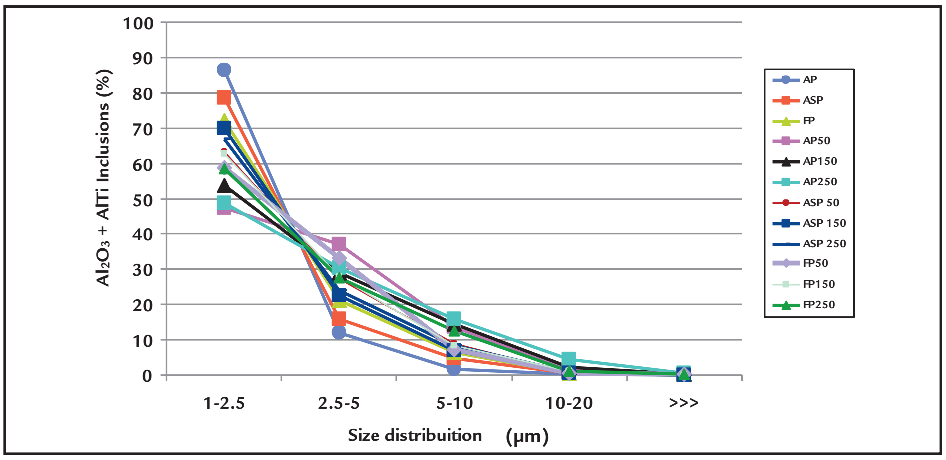


Figure 4
Size distribution
average of Al_2O_3 e AlTi inclusions
in the three different studied process.

Sample	Area Fraction (Al_2O_3)	Area Fraction (AlTi)	Total Area Fraction	Std Deviation total AF	Delta each step %	Delta into Tundih %	Total Density (n°/mm2)	Std Deviation Total Density	Delta each step %	Delta into Tundih %
AP	32	12	44	16			14	4		
AP50	250	23	273	107	523		26	7	81	
AP150	208	24	231	40	-15		20	10	-24	
AP250	191	18	208	60	-10	-24	15	7	-22	-41
ASP	43	10	53	16			11	2		
ASP50	184	29	214	57	304		35	14	232	
ASP150	202	39	241	62	13		51	26	46	
ASP250	183	32	214	61	-11	0	34	14	-33	-2
FP	67	6	73	32			11	3		
FP50	228	26	254	22	247		33	2	200	
FP150	174	26	200	25	-21		28	2	-17	
FP250	165	23	189	27	-6	-26	25	15	-11	-26

Table 2
Area fraction and density
average of Al_2O_3 e AlTi inclusions
in the three different studied process.

a) ***RH inclusionary evolution for the Tundish:*** The three processes present Al_2O_3 and AlTi inclusion pick-up in the tundish expressed by the occupied total Area Fraction, the largest percentage pick-up (523%) being in the heats with Heating and Purging (AP), followed by the heats with Heating and No Purging (ASP) with 304%. The best result was observed in the heats with Tundish for Cold and Purging (FP) that had an inclusionary pick-up in the Area Fraction of 247%. Considering the Total inclusionary Density, the process with Heating and No Purging (ASP) leaves its previous second position and becomes the greater inclusion evolution with a 232% increase in RH Density for the Tundish. This behavior would be the most expected, as this tundish type does not have the previous Purging, which favors oxidation, as shown by Tanaka *et al* (1993), Zang and Thomas (2003) and Yanyan *et al* (2013).

The largest pick-up in the tundish with Heating and Purging (AP) was not expected, because according to the Jen-Hsin *et al* (2003) experiment, due to its high temperature, in the warm tundish, the oxygen present is 20.9% smaller than a cooling tundish. The tundish's greatest temperature, besides reducing the air volume inside the refractory container, according to the Miki *et al* (1999) experiment, promotes different behavior from the steel flow inside the tundish, with a rising tendency to buoyancy and greater circulation, thus favoring steel cleanliness. An explanation for this might be the abnormal pick-up of one of the group heats, either for a non- registered purging defect or some air flow between ladle and tundish.

b) ***Inclusions behavior during Casting:*** As expected, the process with Heating and No Purging (ASP) presented the worst reduction result for inclusion Area Fraction during the casting, given the lack of purging, greatly adding to the tundish's initial inclusions, as already shown. The other two processes, Heating with Purging (AP) and Cooling with Purging (FP) presented similar performances, with a 24% and 26% reduction respectively in the inclusionary total, showing that the initial purging of the last two processes might have made the difference, as discussed previously. That improvement inclusionary tendency along the heats is explained by Sahai e Emi (2008) mainly by the renewal in the tundish of a cleaner steel coming from the pot, as well as the tundish's own capacity to remove inclusions through its synthetic slag.

c) ***Size of the Inclusions:*** The average general distribution of the inclusion size in RH and in the Tundish follows the great majority of inclusions (47%~86%) concentrating on the smallest range between 1µm to 2.5µm, followed by 12%~37% of the inclusions in the range between 2.5µm to 5µm, 2%~16% in the range between 5µm to 10µm and 0~5% between 10µm to 20µm, with no inclusion above 20 µm. The distribution of inclusion size in the tundish is quite favorable to steel cleanliness. According to T. Emi (2005), there are very few occurrences of inclusions above 10µm and none above 20µm.

The high standard deviation values for both, total area fraction and total density, shows how inclusion measure are sensitive to operational variables, sampling and analysis practice. Results in the ladle show more stability with a lower standard deviation, probably due a more stable homogenization condition of the ladle process. Meanwhile in the tundish, the results are more impacted by the unstable conditions of the tundish fluxes, especially during its first heat filling.

4. Conclusions

Al_2O_3 and AlTi inclusions are the two majority inclusion groups presented in an IF aluminum killed steel, both representing 90% of total inclusions;

Al_2O_3 inclusions occupies proportionally seven times more area than AlTi inclusions, and its volumetric size distribution is as follows: 85% <=10µm, 15% between 10µm~20µm and 0% > 20µm. This size distribution was not affected by the different studied processes;

All three processes presented inclusion pick-up from RH to the Tundish and as expected, tundish purging showed to be the most more efficient than that with no preliminary Purging process, especially during a tundish sequence;

The heating process showed a similar tendency evolution when compared to the cold tundish, for both, RH-Tundish pick-up and inclusion reduction along the tundish sequence;

Finally it is concluded that previous purging of the tundish has an important role in minimizing RH inclusion pick-up for Continuous Casting, proving to be more important than heating the tundish. The tundish with no purging had the worst result and the cooling tundish with purging had the best general performance.

5. Acknowledgements

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