LONG STEEL CASTING WITH FLEXIBLE SYSTEM FOR OPEN AND SHROUDED STREAM*

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Abstract

The CNC Shrouded*is a tundish flow control system that allows the cast of long products in both open or shrouded stream from tundish to the mold. This allows steel of higher quality to be cast by protecting the stream from the re-oxidation from atmosphere as well as the usage of flux powder as lubricant, which also improves quality in terms of surface and thermal exchange with the mold. The trials were conducted to validate the proposition and evaluate the differences in terms of quality, considering surface of the billet,and as a second step, chemical analysis of samples. The preliminary results have proven the system improves significantly the quality, by having a much better surface quality as well as no re-oxidation, while being of simple usage operationally and of lower cost compared to other systems where there is flow control, such as tundish slide gate or stopper and submerged entry nozzle.

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Keywords:CNC Shrouded; Billet casting; Unshrouded casting; Long carbon steel quality increase.

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1 INTRODUCTION

Production of long carbon steel is usually made through open stream from the tundish to the mold, with the exception for special steel grades, that require protection from atmosphere to preserve quality mainly. To protect the stream from re-oxidation and reduce turbulence in the mold, steel plants use submerged entry nozzle or submerged entry shroud. To protect the meniscus from contact with the atmosphere, is used flux powder, which plays other roles such as heat transfer control from steel to the mold as well as mold lubrication[1].

However, some steel grades, which are currently cast through open stream does not meet sufficient quality criteria, or a lower inclusions level is desired, or even an improvement is needed in terms of surface quality of the billet. Some solutions are developed to minimize the effects of re-oxidation, such as a protection can with argon flow (or nitrogen) inside to create an inert atmosphere, as it can be observed on **Figure 1**.

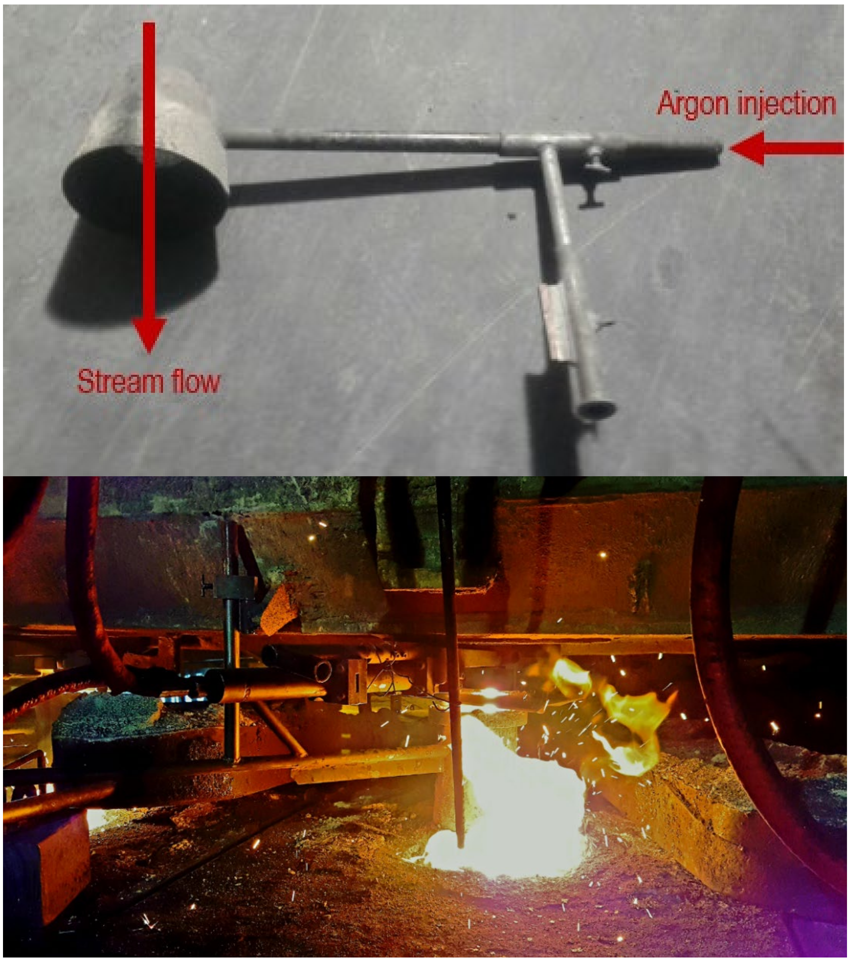

Figure 1: Example of a device for argon injection to create an inert atmosphere. Severe turbulence, as it may be observed through the steel splashes, besides the fire, indicates low effectiveness of this solution.

However, such solutions are of difficult implementation and produce low effect on quality, as the gas available on steel plants have impurities, there are gaps when placing the can around the mechanism below the tundish and above the mold, allowing severe air aspiration, among other problems, besides having no effect on mold turbulence, hence on mold level variation, as well as on surface quality of the billet cast.

This motivated the development of a flexible system which can operate both in open stream, and when required, in a shrouded stream, to achieve optimal quality in terms of inclusions as well as surface quality of the billet at a low cost and low complexity of operation.

The refractory stack up as well as mechanical parts are described on **Figure 2**, where items with * are of regular use on unshrouded casting.The installation of the CNC Shrouded system is similar to a CNC conventional system. It uses the same top plate refractory and same mechanism, however, with added parts and refractories. A similar lower plate (here called "Center plate") is placed to be used and changed whenever desired to control speed by the change of the diameter, as well as a bottom plate is added, where the Shroud will be connected to.

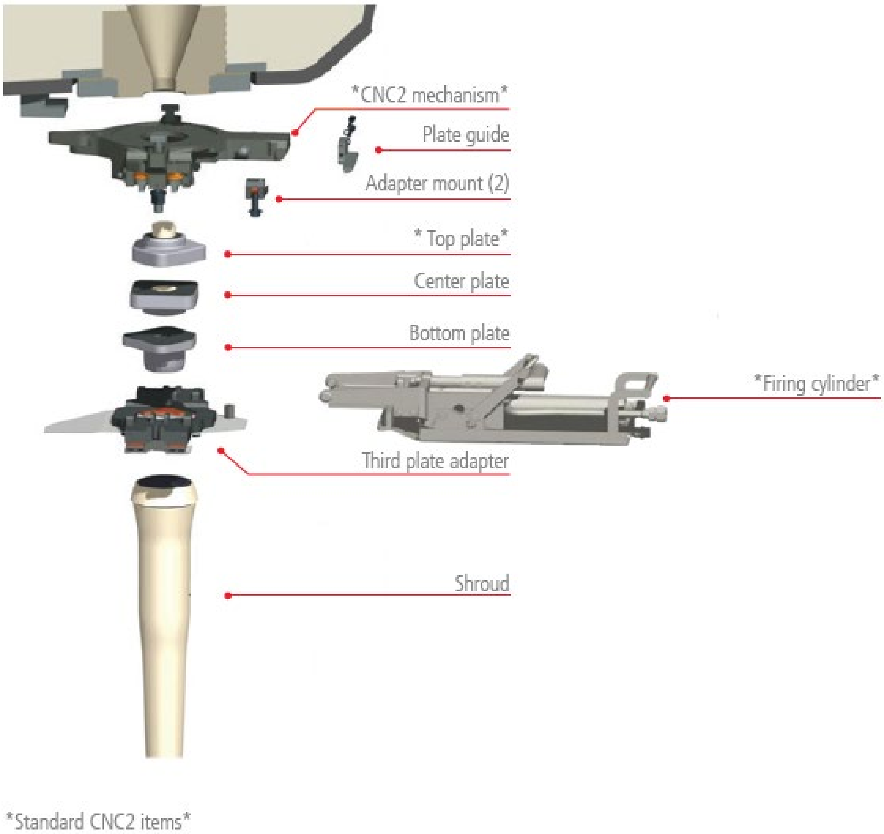

Figure 2: Stack up of refractories and mechanical parts for the CNC Shrouded.

This allows the steelplant to operate using both types of casting, shrouded and unshrouded. Also, allows the usage of either oil or flux powder as lubricant, depending upon the quality requirements.

The motivation to both plants that ran the trials conducted, was to produce higher quality steel grades, such as leaf spring for automotive industry, than their current portfolio more focused on civil construction steel grades.

2 DEVELOPMENT

2.1 Casting Start Trials

Prior to the trials, it was studied the optimal layout for casting start. Current practice is opening the strand by pulling the rope and using oxygen lance. Doing so, it is required for the stream to stabilize and then place the Shroud within the open stream. In order to start casting directly with the Shroud, without the need to place it after casting start, trials were conducted to develop a method that requires no interference such as oxygen lancing. The layouts found on the **Figure 3**, **Figure 4** and **Figure 5**below were tried, and the optimum was placing the metal starter tube with swarf around it, in order to stabilize it in place once the molten metal reaches it. On all trials with this last layout the strand opened within 90 seconds to 150 seconds, depending on the steel temperature, among other variables.

Figure 3: First starter tube, with opened top and mortar setting.

Figure 4: Second starter tube, shallow, with opened top and mortar setting.

Figure 5. Third starter tube, with 240mm height, closed top with swarf setting.

2.2 Trials Set-ups and Results

The trials were conducted comparing the regular strand (number one) against the strand equipped with the system (number six at AM Resende and number five at AM B Mansa), over several times, with different set ups, as described below on **Table 1**.

Table 1. Trials set ups.

Trial No.	Plant	Initial Heat No.	Argon	Lubricant	Heats Cast	Shroud
1	AM Resende	52076	No	Oil	3	1 x BX06240
2	AM Resende	52255	No	Oil	7	2 x BX06240
3	AM Resende	56546	No	Oil	6	2 x BX06240
4	AM Resende	56566	Yes	Oil	7	1 x BX06240
5	AM Resende	56399	Yes	Oil	6	1 x BX06240
6	AM Resende	56424	No	Powder	5	2 x BX06083
7	AM Resende	56472	No	Powder	6	1 x BX06083
8	AM B Mansa	73592	No	Powder	5	2 x BX06083

The following data presented and discussed are relative to trial number 5 and 6.

The refractory tube was preheated to temperatures around 900ºC to 1000ºC. The preheating has two main reasons, first to avoid steel freezing inside the tube, and second, to fulfill thermal requirements of the refractory for usage, as illustrated on **Figure 6**.

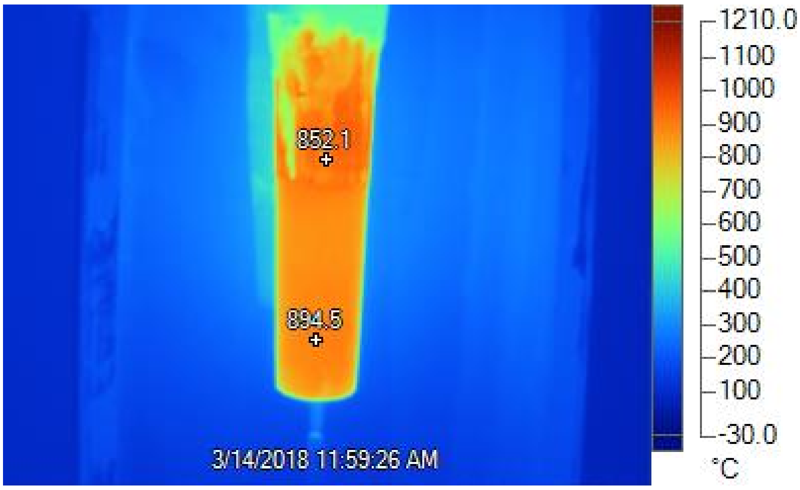

Figure 6: Thermographic image of tube during preheating.

After preheating, the refractory is placed as per the stack-up on **Figure 2** and the strand is started. On the **Figure 8** below it can be observed the difference of layout of the system compared to the current standard operation.

Figure 7: Casting from tundish to mold with open stream (right-hand side) and Shrouded stream (left-hand side).

Several variables were evaluated on these trials, such as mold level and casting speed, as observed below on the **Figure 8**, as well as temperature UED (Extraction and Unbending Unit), as observed on the **Figure 9**where it may be observed that the surface temperature of strand number 6 is within the standards, which ranges from 900ºC to 1100ºC. An important highlight from these thermal images is that the strand of the trial showed much better thermal distribution on the billet, due to the usage of flux powder, which controls heat transfer more homogeneously and precisely than oil.

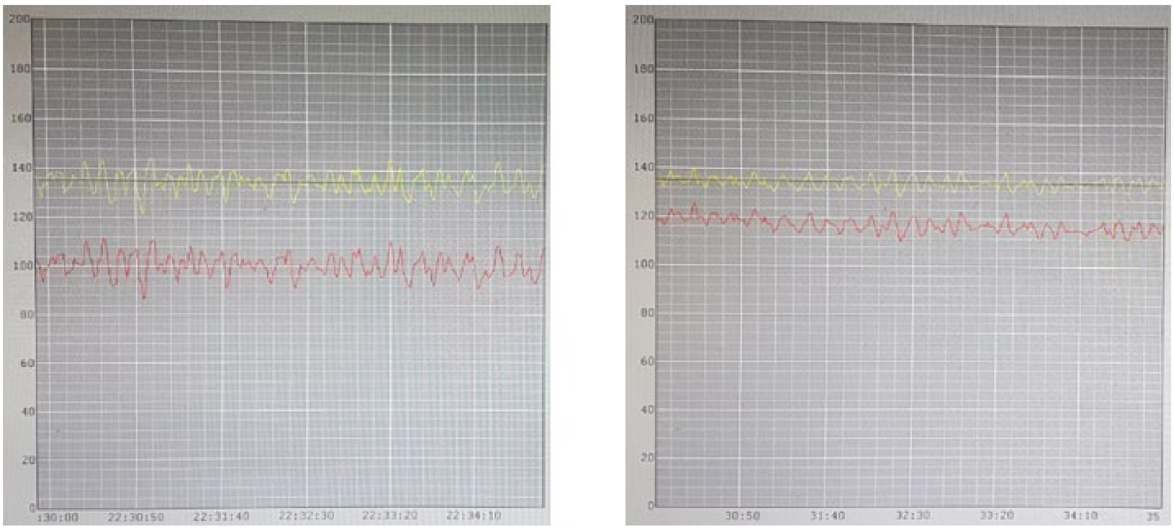

Figure 8. Comparison between strand number one (left) and strand number six (right) for trial on heat 56424 in ArcelorMittal Resende, in terms of casting speed in red (m/min – scale not shown) and mold level in yellow (mm).

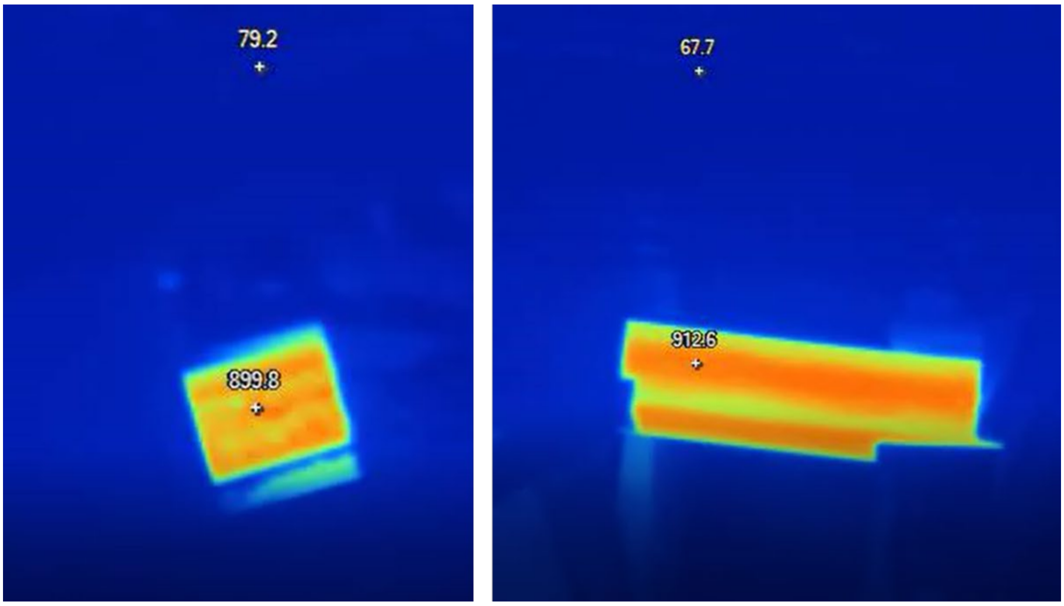

Figure 9. Thermographic images of the UED (Extraction and Unbending Unit) shows temperature within the standard range during trial No. 4, and more uniformity on temperature on the strand of the trial. Left-hand side is strand 1 (regular) and right-hand side is strand 6 (trial).

After casting, it was compared the surface quality of the billets, as seen below on **Figure 10**. It can be observed that it was significantly improved with the usage of the shroud combined with flux powder.

Figure 10: Comparison of a regular billet cast with opened stream (strand 1 – left) and a billet cast with CNC Shrouded with flux powder (strand 6 – right).

After visual inspection of the billets, 3 samples were taken for blasting, as illustrated below on **Figure 11**. It may be observed that the surface quality improves significantly from Samples A to C, where the latter showed the best results, being cast with the shroud combined with flux powder.

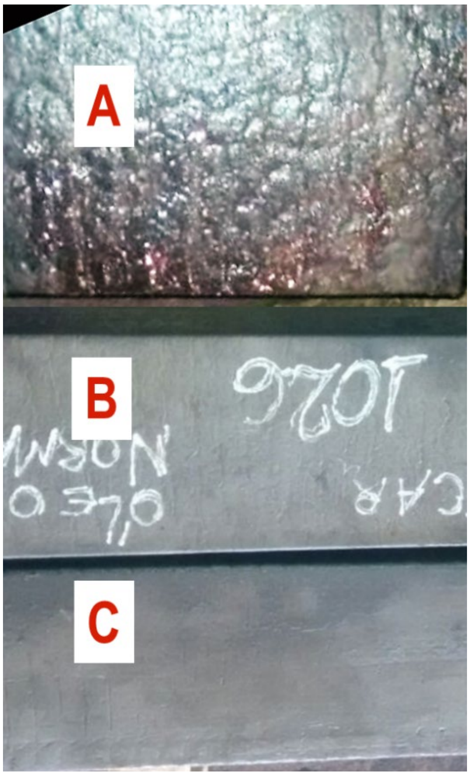

Figure 11: Samples of billets after blasting. Sample A was the standard open stream with oil (strand 1), Sample B was from trial number 5, cast with the shroud and oil as lubricant, and Sample C was from trial number 6, cast with the shroud and flux powder as lubricant.

Heats number 56404 (cast with CNC Shrouded and oil) and 56428 (cast with CNC Shrouded and mold powder) were chemically analyzed on an inclusion study compared with another sample of regular casting (open stream and oil). The study consisted on analyzing 100mm² of samples, identifying inclusions of 2 microns of minimum size on an ASPEX Explorer automated SEM.

The following rules were used for classification, as seen on **Table 2**:

Table 2. Classification rules for inclusions analysis.

Inclusion Type	Classification Rules (At %)
MnS Rich	Mn>25 and S>10
Al Rich	Al>35
CaSi	Ca>5 and Si>5
MnSi	Mn>20 and Si>10

For this steel grade (ABNT 1026) CaSi are typically steelmaking inclusions, originated from the process, and the CaAlSi ternary diagrams below, on **Figure 12**,shows the amount of these inclusions on each heat:

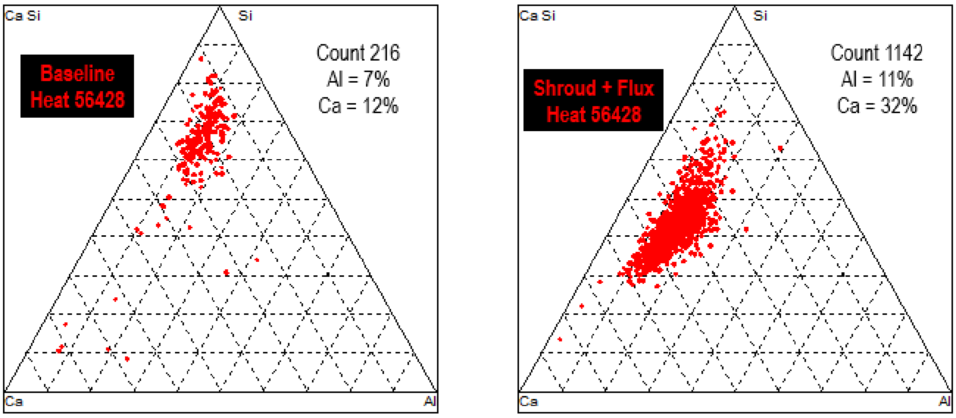

Figure 12: CaAlSi ternary diagrams comparing the strand with CNC Shrouded and mold powder against the baseline strand, with open stream and oil.

On the diagrams above it can be observed that on the trial sample the amount of inclusions is higher. However, this means that the steel was made with this level of inclusions, and that in fact they were re-oxidized on the open stream sample. Hence, that the sample of the trial can be compared to a sample taken from the tundish, regarding CaSi inclusions. Unfortunately, the samples with CNC Shrouded and oil and its baseline cannot be fully comparable since they were taken from different heats, hence will not be shown on this paper.

The same results can be seen on another analysis, which is regarding MnAlSi ternary diagrams, where MnSire-oxidation type inclusions, which are typically formed due to the contact with atmosphere,are shown. On the**Figure 13** below it can be seen a comparison, with CNC Shrouded and mold powder compared to its baseline.

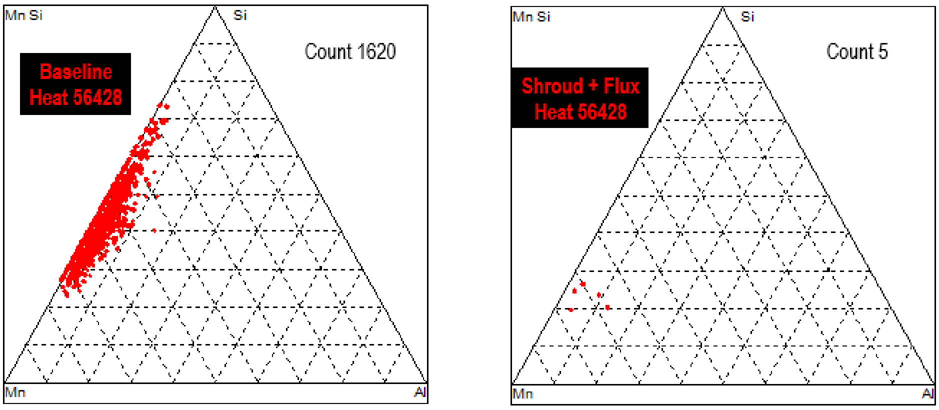

Figure 13: MnAlSi ternary diagrams comparing the strand with CNC Shrouded and mold powder against the baseline strand, with open stream and oil.

As seen above, the count of these type of inclusions are 5 on the sample strand against 1620 on the regular one, which represents 99,7% reduction. This shows the effectiveness of the system, as these kinds of inclusions are formed due to the contact of the steel with the atmospheric oxygen.

Higher CaSiand Al rich inclusions count, as well as higher percentage of Ca and Al indicate less re-oxidation in CNC Shrouded and mold powder sample. Lower MnSi count and percentage of Mn confirm the same. As per Ellingham Diagram, seen on

Figure 14, oxygen activities are increasing from Al_2O_3 to SiO_2 to MnO, thus, added MnO comes from re-oxidation.
These data can be seen on the**Table 3** and **Table 4** below, where shows other aspects of the chemical analysis performed on the samples:

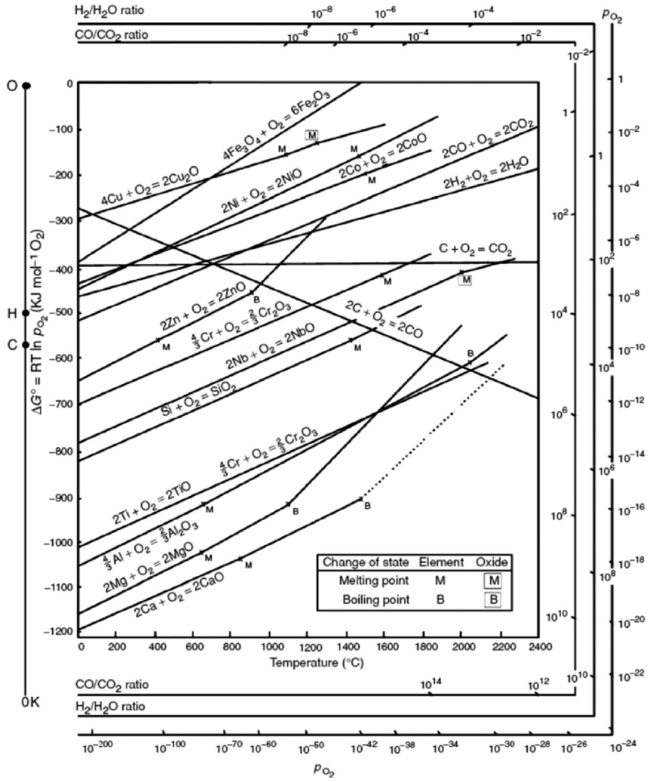

Figure 14: Ellingham-diagram for the formation of oxides based on their standard free energy of formation over temperature³.

Table 3. Inclusion count.

Grade	Heat	Condition	MnS Rich	Al Rich	CaSi	MnSi	Total Oxides
1026	56428	Open + Oil	1011	27	216	1620	1863
1026	56428	Shroud + Flux	176	62	1142	5	1209

Table 4. Average composition in percentage.

Grade	Heat	Condition	Ca	Al	Si	Mn	S
1026	56428	Open + Oil	0.01	0.02	0.22	0.44	0.27
1026	56428	Shroud + Flux	0.25	0.13	0.25	0.21	0.10

Other important points to highlight is the reduction on MnS rich inclusions, which is an important control item on the production of this steel grade, as well as an increase on alloy elements such as Ca and Al on the sample cast with CNC Shrouded and mold powder. However, more trials are recommended to confirm these phenomena.

2.3 Further Steps

Besides a better surface quality and inclusions level, there are more gains to be studied from this project such as metallic yield on alloys, reduction of surface scale, which will increase productiveness of the caster, and yield increase on rolling mill from a lower rejection rate due to this higher quality of the billet.

However, with the results already obtained, the Steel Plants where the trials were taken will convert to this system, and more can be studied in an industrial scale.

3 CONCLUSIONS

Casting with mold powder in a Shrouded stream enhances quality, as mold level variations are narrower, as well as steel contact with the atmosphere and oxygen are virtually inexistent. There is a much cleaner and safer environment by using a Shrouded stream against an opened stream, due to oil droplets and the steel flow being protected.

The billets were approved by the better surface quality, as well as for inclusion analysis, which showed great effectiveness of the system, and further trials will be conducted to evaluate macrography of the billet and to capture more gains from this project.

4 AKNOWLEGMENTS

We would like to thank Sr. Associate Research Mr. Roger Maddalena and his staff at Vesuvius Pittsburgh R&D Center for the report prepared on Inclusion Study and SEM Analysis, which was paramount for the understanding and quantification of the improvements.

We would also like to thank all the operators from the continuous casting machines of both Barra Mansa and Resende plants, who collaborated significantly for the trials to be performed, especially Mr. Carlos Francisco.

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