RHI'S SOLUTIONS TO REDUCE STEEL DEFECTS*

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Abstract
Based on a short overview regarding steel defects in the final product, several refractory approaches to maintain or increase steel cleanliness are reviewed in this publication. By applying a ladle to mold approach, one potential to maintain cleanliness is to reduce the probability of air ingress by selection of a suitable slide gate system. Following this path, also the influence of a special configured impact pot is presented to maintain steel quality. Finally, higher productivity as well as cleanliness can be provided by selection of PROIL as a revolutionary product at the casting machine.

Keywords: Defects; Ladle-To-Mold; CFD; Continuous Casting.

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1 INTRODUCTION

Continuously cast semis can suffer from differing defects caused by various factors, occurring separately or contemporary during steel production. The origin of these defects can be found in variations in the secondary metallurgical treatment as well as during ladle to mold transfers, whereas some defects can already be traced back to tapping at the EAF/BOF. Solidification related defects due to mold issues may also have their origin in entrained non-metallic inclusions (NMI), tundish slag or mold flux.
Stresses applied to the solidifying steel shell by the supporting rolls in the secondary cooling zone, or also the cooling agent and/or type of nozzle can again decrease the product surface and sub-surface quality, if no attention is paid on the machine maintenance.
Besides, also refractory products are known to have a big influence on steel cleanliness and quality. Interaction of refractory linings with steel and/or slag, clogging of ladle-to-mold products like slide gates, as well as wear of isostatically pressed (ISO) products by mold fluxes, are only some examples that can lower productivity.
The aim of this publication is to provide a general overview on typical defects in continuously cast steel with some possible origins and approaches to prevent them. The focus however lies on potential refractory approaches by RHI to help maintaining or even increasing steel quality at the continuous caster.

2 POTENTIALS TO REDUCE DEFECTS

Process related issues during the steel production process as well as defects in the final product can lower the mechanical properties and also lead to decreased productivity. The enumeration of all possible defects occurring during steel production and potential causes thereof would exceed the volume of this paper. Moreover, surveys about steel cleanliness and ways to avoid contamination are already published elsewhere [1-3]. **Figure 1** presents only some examples of possible defects that may occur in the final product and lower quality.

Figure 1: Potential defects, influencing the quality of the cast product.

RHI as a refractory supplier is continually engaged in further improving the functionality of its products for the continuous casting process and in developing new concepts for the so called ladle-to-mold flow control products. The idea behind these improvements is to help the customer to maintain or increase steel cleanliness.

Increasing the quality of the casted product sustainably by decreasing one or more of defects in the cast semis can only be achieved by using also a holistic approach regarding refractory selection.

Steel cleanliness starts already at tapping from the EAF/BOF and in some cases already at the scrap selection. Alloy and additive selection, moment of addition, treatment times, as well as process control during each step are essential to achieve the steel quality during the secondary metallurgical treatment.

Beside metallurgical steps, shrouding and adequate refractory selection are also essential parameters to minimize interaction of the metallurgical vessel lining, furniture or isostatically pressed products with the steel and/or slag. These measures can help to keep the contamination of the liquid steel by exogeneous and endogeneous inclusions low and maintain caster productivity.

Amongst the products that play an important role in controlling liquid steel flow from the ladle down to the mold, there are ISO products, such as submerged entry nozzles/shrouds (SEN/SES) and exchangeable submerged nozzles (MT). Ladle slide gate systems and refractory product quality play a critical role as well. One example regarding the beneficial influence of novel ISO products on steel cleanliness as well as caster performance can be taken out of [4].

New technologies not only include material innovations for higher wear resistance to increase also sequence length, but also do they provide functionalities that can significantly help controlling and improving the continuous casting process.

2.1 LADLE TO TUNDISH INERTIZATION

The influence of re-oxidation on cleanliness and potential locations of air ingress into the steel are already summarized by other authors [5, 6]. The main driver for air ingress at the ladle slide gate as well as at the joint between the collector nozzle and ladle shroud is a negative pressure created during steel flow throttling. Minimizing this negative pressure by optimizing the casting diameter to the actual caster demand is the first measure to reduce air ingress probability.

Furthermore, in relation to re-oxidation potential, the design of slide gate plates also regarding thermo-mechanical stresses has to be taken into account. Cracking during operation may lead to potential air ingress and to oxygen pick-up and NMI formation, as well as plate wear and thus reduced casting control [6].

Previously published results of Ehrengruber et a. [7, 8] proved the potential to provide a 100% oxygen free atmosphere around the throttling position between the slide gates by adding inert gas purging. The benefit of an effective inertization system is a very low nitrogen pick-up, which is an indication of oxygen pick-up, as shown in **Figure 2**.

This measure should be carried out using the so called shielded shroud connection (SSC) application to ensure the lowest reoxidation potential (**Figure 3**). As already published elsewhere [9], the SSC application provides a reliable prevention of air aspiration at the joint between the exchangeable nozzle and the ladle shroud (LS). This can be achieved by controlled supply and maintenance of a positive argon pressure over the entire nozzle/shroud sealing interface [10].

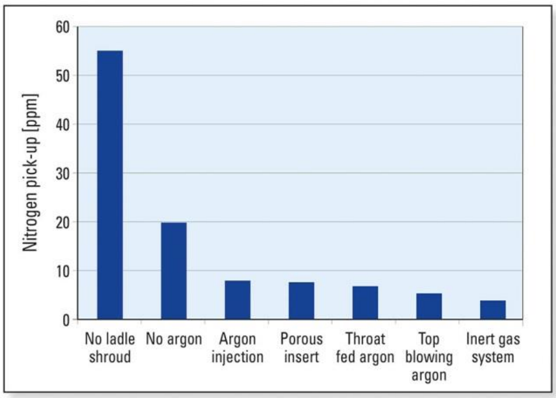


Figure 2: Effectiveness of ladle shroud inertization measured by nitrogen pick-up [ppm].

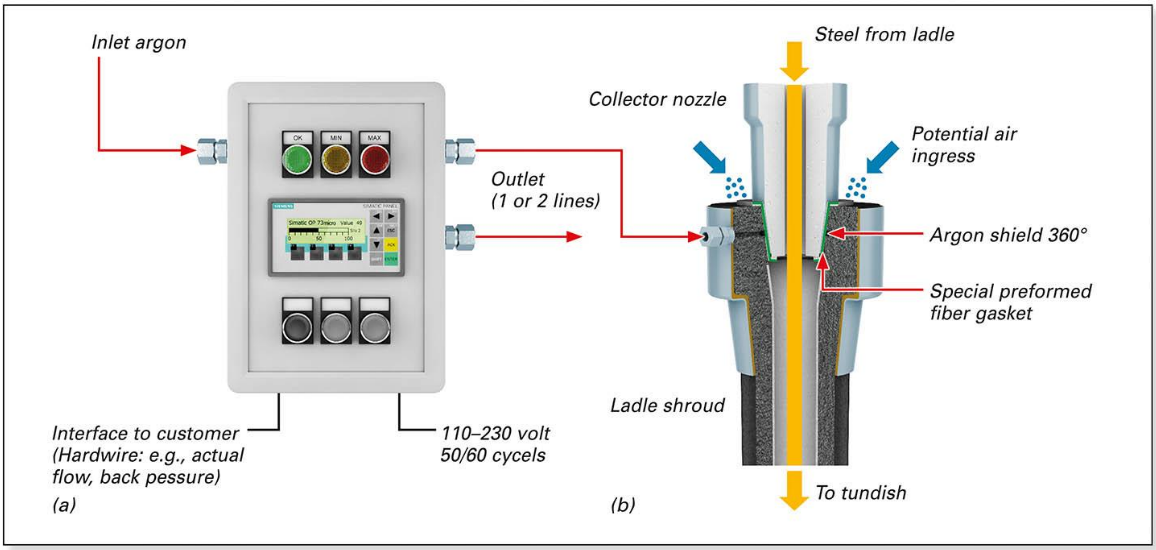


Figure 3: Shielded Shroud Connection (SSC) showing (a) the controlling unit and (b) the connection of the collector nozzle with the ladle shroud.

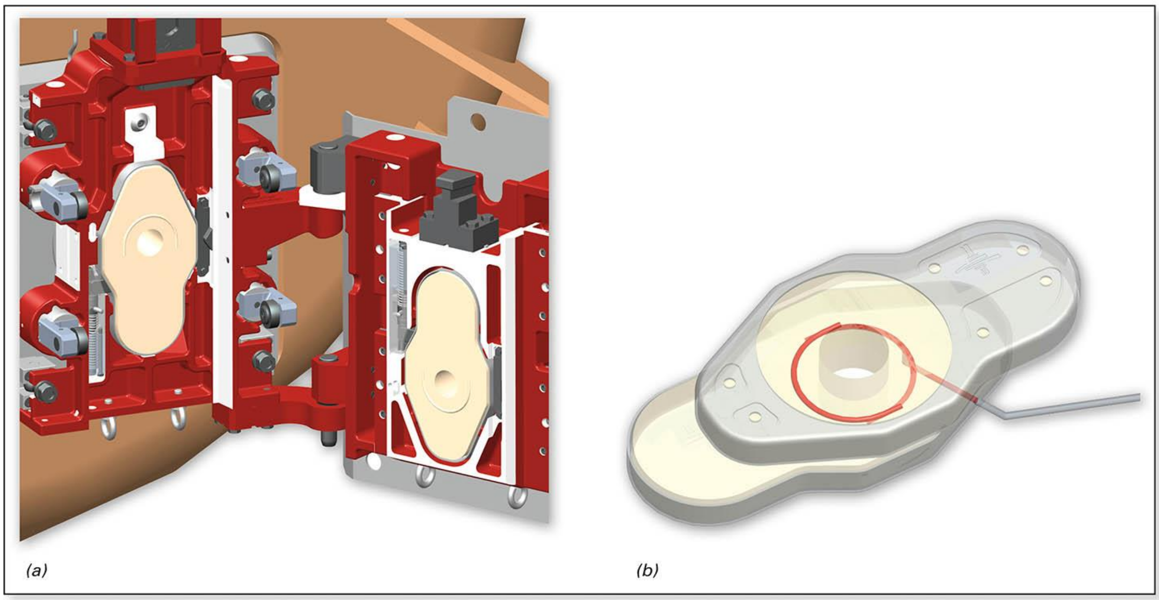
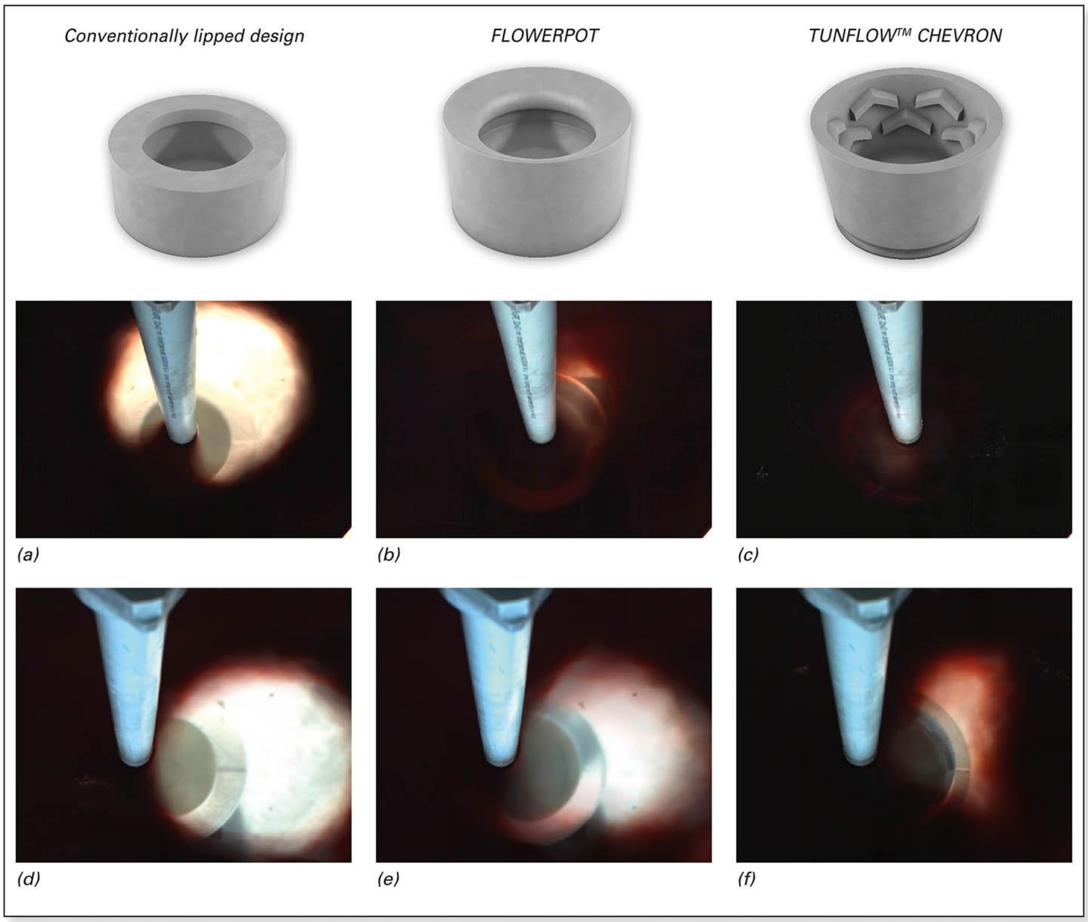


Figure 4: (a) INTERSTOP S slide gate configuration and (b) inert gas purging between the plates provides a 100% oxygen-free atmosphere.

2.2 TUNFLOW™ – cleanliness by competence

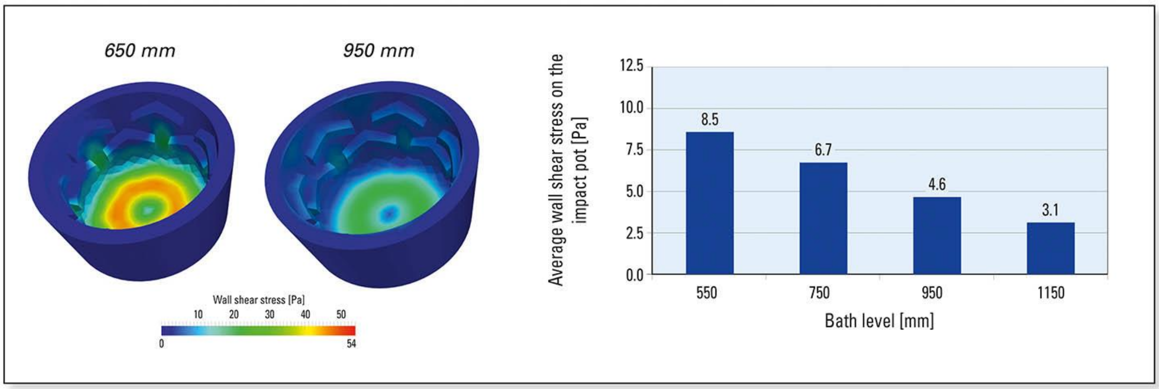
The previous part dealt with an overview on the SSC shrouding approach during the ladle-to-tundish transfer, ensuring low to no re-oxidation and thus guaranteeing a high steel cleanliness level. Following the steel production line, the next area of interest addresses the impact pot below the ladle shroud. Only few works has been published dealing with this topic and if, aligning the ladle shroud perfectly vertical or slightly misaligned is the main varying factor. This part goes more into detail regarding impact pot design and adjustment to tundish size.
Table 1 shows representative snapshots for the characterization of surface turbulence and "open eye" formation obtained by a water model benchmark. Three different impact pot designs assuming a perfectly vertically aligned shroud (a, b, c), as well as an 1.5° inclined LS (d, e, f), were compared. The installation of RHI's FLOWERPOT leads to a significant decrease of the open eye compared to a conventional lipped design, for vertical as well as inclined LS. Using the TUNFLOW CHEVRON, the surface turbulence can be further reduced and, as a consequence, the open eye formation almost completely avoided for a perfectly aligned LS (**Table 1**, c). Even if there still is an open eye formation with the CHEVRON design at a misaligned shroud (**Table 1**, f), the superior performance compared to the other cases (**Table 1**, d & e) is obvious. Details to similar simulations with misaligned ladle shrouds can be taken out of [11, 12].

Table 1. Influence of impact pot design and LS alignment on surface turbulence



As mentioned previously, shroud immersion depth [5], ladle slag carry over and impact pot selection have a significant influence on the metallurgical performance of the tundish, hence the product quality. Nevertheless, a so called piston streaming or plug flow in the tundish is also desired. Again CFD simulations were carried out for a round impact pot design. The distance of the ladle shroud outlet to the impact pot was varied to determine changes regarding tundish surface turbulence and stresses applied to the impact pots. Tundish bath levels of 550, 650, 750, 850, 950, 1050 and 1150mm were set as boundary conditions during these simulations. The tundish steel throughput was set 3.6 t/min, the LS immersion depth adjusted to 339 mm.
Table 2 shows the average wall shear stress over the whole impact port area, the average turbulent kinetic energy over the whole tundish top surface at different tundish bath levels is presented in **Table 3**. The immersion depth of the ladle shroud in the bath was the same for all cases and thus the distance from ladle shroud tip to the impact pot bottom was varied. It is very clear from **Table 2** that the higher the bath level, meaning a longer distance of the LS outlet to the impact pot bottom, the less averaged wall shear stress is applied on the whole impact pot area.

Table 2. Wall shear stress at varying bath levels



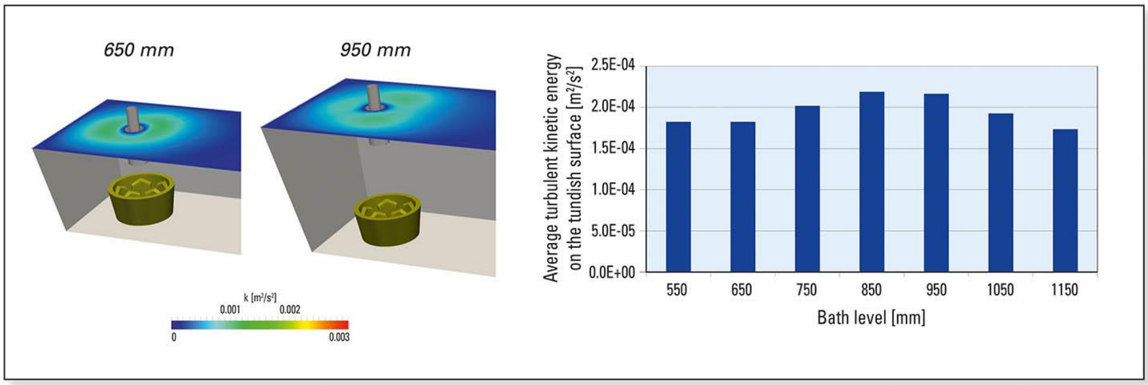
The calculated wall shear stresses distributions are depicted in **Table 2** for different ladle shroud distances. The main stress area for sure is focused at the bottom, where the incoming steel stream is calmed down and redirected back to the tundish surface. A clear explanation of the weighting of these stress values regarding impact pot material behavior cannot be provided at the moment. The influence of different material grades in more and less stressed areas of the impact pot will be part of a separate upcoming publication. Still, it is clear that increased tundish performance regarding steel cleanliness will go hand in hand with enhanced impact pot lifetime, which makes material selection more and more a key value for performance besides impact pot design.
Table 3 contains the results of CFD analysis regarding the tundish surface turbulence kinetic energy distribution at bath levels of 650mm and 950mm by the application of TUNFLOW CHEVRON. Compared to other impact pot formats (like **Table 1**), the TUNFLOW CHEVRON can reduce rather a lot of turbulent kinetic energy on the tundish surface. Exemplarily, results revealed that the maximum turbulent kinetic energy on the tundish surface using the CHEVRON design is almost below 0.001 m^2/s^2. For other impact formats, this value was found to be around 0.002 m^2/s^2). As a further result out of this CFD benchmark simulation, the average turbulent kinetic energy value stays almost at the same range at varying bath levels

** Technical contribution to the 48º Seminário de Aciaria, part of the ABM Week, October 2nd-6th, 2017, São Paulo, SP, Brazil.*

from 550mm to 1150mm. This indicates the very good performance to reduce turbulent kinetic energy at low bath levels, if the CHEVRON design is applied to the process.

However, it also has to be stated that these values are for sure not valid for every tundish, due to the high variability of casting parameters like steel throughput or ladle shroud size. Anyhow, it seems to be clear that in addition also the impact pot size, general shape as well as design details [13] will have an influence on tundish behavior. Contemporary, the correct selection of impact pot material will also be a key to ensure longer lifetime of the tundish furniture and lining, leading to a more stable process, thus maintaining or increasing steel cleanliness.

Table 3. Influence of impact pot design and distance to ladle shroud exit on surface turbulence



2.3 PROIL – The next revolution for billet & bloom casting

PROIL is working as a liquid slag of a casting powder pumped at room temperature into the mold by a simple feeding assembly. Detailed information regarding development and procedural benefits can be taken out of [14]. The solid component of PROIL is a conveniently formulated casting powder dispersed in synthetic oil. The casting powder itself melts rapidly at the expenses of heat, produced by burning-off of the liquid medium (oil). This feature is perfectly matching normal operations of continuous casting of long products in open steel stream, where thermal insulation of liquid steel bath is not an issue.

Results regarding cleanliness investigations using PROIL versus oil and mold flux are presented in **Figure 5**. The number of non-metallic-inclusions (NMI) is clearly lower than using common mold flux, and the results are equal to the use of oil, but with lower deviations.

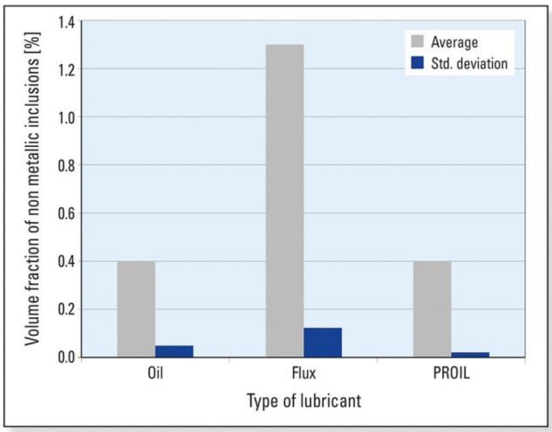


Figure 5. PROIL – Cleanliness compared to the use of mold flux and common oil.

Other benefits of PROIL are graphically depicted in **Figure 6**, the advantages regarding steel cleanliness, surface and sub-surface defect reduction can be deduced easily: In comparison with normal natural or synthetic oil used in open steel stream, liquid powder is surely

- adding effective lubrication, and more important
- adding control capability of heat transfer between strand and mold wall,
- resulting in mild homogenous cooling, and
- leading to a significant increase of effective length of the mold.

Consequence of this situation is a large tide of noteworthy effects such as

- a strong rombohedricity reduction,
- a considerable drop in scale formation, and
- a major increase of casting speed

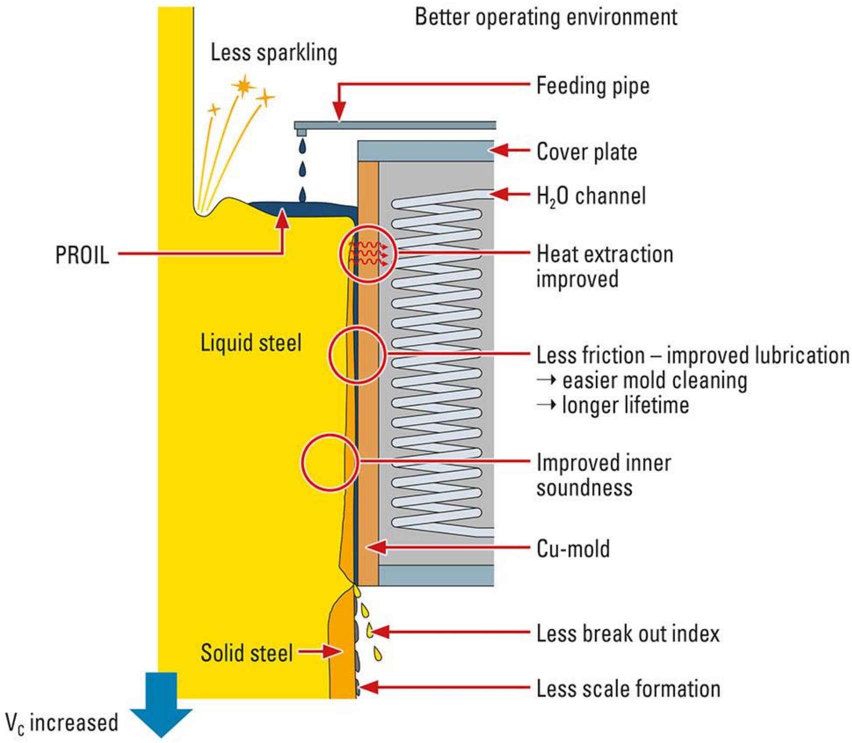


Figure 6. Advantages of PROIL obtained by industrial trials.

Figure 7. PROIL – Feeding equipment and product appearance on industrial scale.

3 SUMMARY

A short overview on steel defects, their origin and avoidance introduced the potential of refractory products to help maintaining or increasing steel cleanliness. Focus thus was set on three different refractory solutions in a ladle-to-mold approach, namely inertization from ladle to tundish, turbulence reduction using adequate impact pots, as well as a novel mold lubrication media, namely PROIL.

Inertization using e.g. the SSC assembly during steel transfer is the first measure to avoid re-oxidation by potential air ingress through the slide gate system, and/or the ladle shroud connection. The thermo-mechanical design of slide gate plates is an additional key to maintain steel flow control and avoid cracking as well as wear of the plates.

The general shape as well as design parameters of the impact pot are connected to surface turbulence as well as tundish layout and casting parameters. Industrial trials proved the beneficial effect of TUNFLOW products on increased cleanliness, reduced open-eye formation, lesser re-oxidation as well as decreased lining wear, leading to increased sequence times, thus elevated productivity.

The novel product PROIL is the best example that enormous benefits can be achieved if also radical changes are taken into account, in this case at the caster. Besides the high potential for increased productivity at the caster, other influences like a better working environment or an increased inner soundness of the cast semis, amongst others, are only some of the advantages of this revolutionary product. **Figure 8** summarizes the previous mentioned facts achieved by industrial trials.

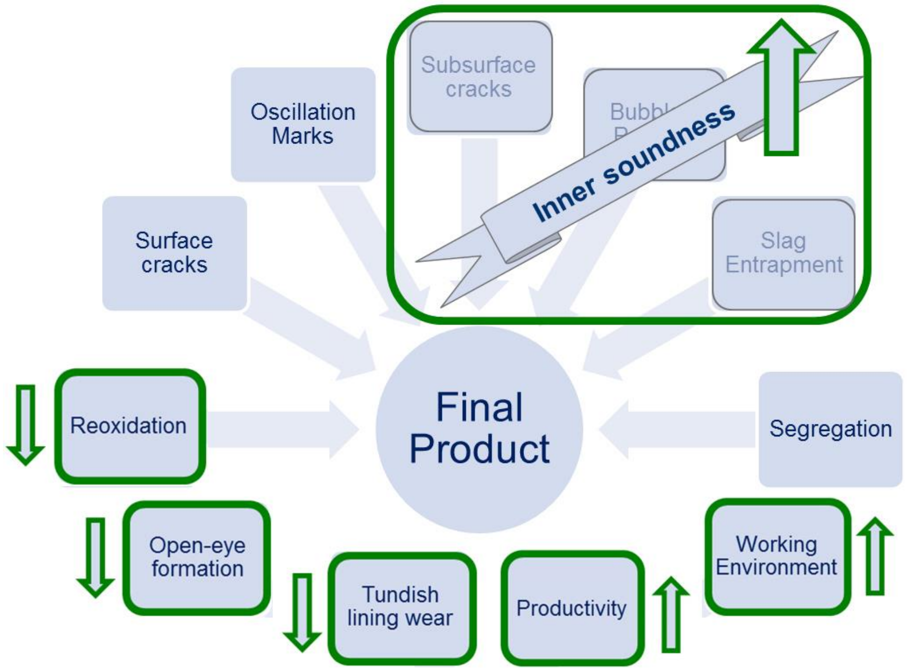


Figure 8. Beneficial effects of only some refractory solutions from RHI.

4 CONCLUSION

Maintaining and increasing steel product quality and cleanliness can only be achieved using a holistic ladle-to-mold approach. Besides metallurgy, correct refractory selection is a key to achieve the goal of elevated steel quality. An inertization system at the slide gate, avoidance of re-oxidation using adequate impact pots, as well as new mold lubricant solutions like PROIL are only some of RHI's contributions to steel cleanliness, surface and sub-surface quality.
Nevertheless, it has to be clear that only one product cannot solve all the issues regarding defects and avoidance thereof, also attention has to be paid on the whole steel manufacturing process, as well as on maintenance of all aggregates in the steel production process.

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