Bulletin — 2024 — pp. 60—67

Rainer Neuböck, Gerald Nitzl, Christoph Eglsäer and Reinhard Ehrengruber

Clean Steel Casting Technology

Refractories and flow control systems for clean steel casting are technology drivers because the demands on steel cleanliness are permanently increasing. Clogging and nonmetallic inclusions in steel not only contribute to additional costs but also have an impact on the continuous casting process due to product downgrades and increased scrap rates. Since low pressures and high turbulence during liquid steel transfer from the ladle to the mould create sources of potential contaminations, special solutions to minimise nonmetallic inclusion formation are required as well as efficient ways to remove them. This starts in the ladle with specialised purging plugs for improved inclusion flotation and ends in the continuous casting mould with modelling to optimise liquid steel flow. Furthermore, in between these two process steps there are refractory systems in the RHI Magnesita product portfolio that can contribute to maintaining high cleanliness of the liquid steel on its journey from a batch process in the ladle to the continuous casting operation in the mould.

Introduction

The term "clean steel" is commonly used to describe steels with low levels of soluble elements (e.g., sulphur, phosphorous, nitrogen, oxygen, and hydrogen), residual elements (e.g., copper, lead, zinc, and magnesium), and above all to define steels with a low frequency of failure due to defects related to nonmetallic inclusions [1]. Both clogging and nonmetallic inclusions affect steel cleanliness and plant productivity in a negative way and in many cases these phenomena are interconnected. For example, clogging in the casting channel affects flow performance and reduces sequence length, while inclusions in the final product can lead to higher scrap rates or downgrading the cast steel. This not only has a negative impact on the conversion costs (Figure 1) but additional resources and energy are required when the steel must be reproduced due to high scrap rates. A fully integrated steel plant generates approximately two tonnes of CO_2 (scope 1 and 2) per tonne of steel [2] and in regions with carbon pricing schemes the cost of these emissions is expected to increase, further exemplifying why the yield improvement of prime quality steel is so important.

Product Portfolio from the Ladle to the Mould

At the continuous caster, a sequence of ladles is poured into the tundish and converted into a continuous process. The liquid steel is then distributed to one or more strands where it solidifies in the mould. As shown in Figure 2, RHI Magnesita can offer all refractory consumables and flow control systems in the complete continuous casting domain.

Clogging and nonmetallic inclusions can form due to contact of the liquid steel with air, refractories, and slag; therefore, controlling these side reactions is key to casting clean steels. As low pressure and high liquid steel turbulence accelerate contact reactions (Figure 3), areas of low pressure need special solutions to protect the liquid steel from detrimental air ingress into the casting channel. This can be achieved by adopting innovative sealing, shrouding, and inert gas shielding approaches. On the other hand, high levels of turbulence can lead to unwanted refractory erosion and slag emulsification, which can be minimised by reducing and dissipating the turbulence using flow modifiers in the tundish and specially designed subentry nozzles for the mould.

Figure 1.
Clogging and nonmetallic inclusions: Influencing factors on total conversion costs.

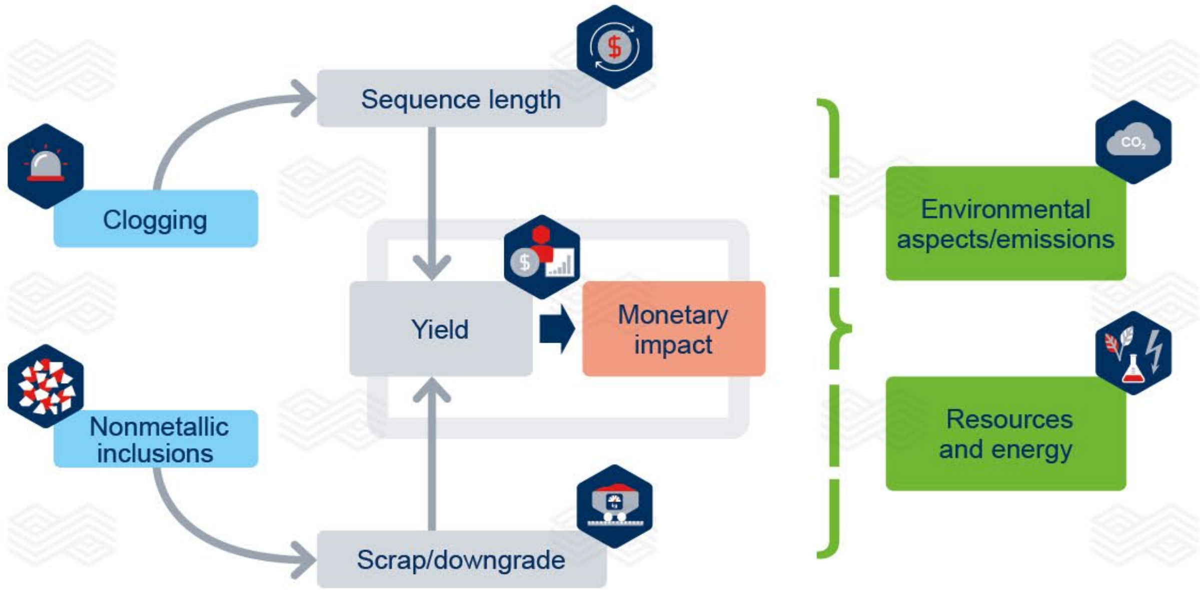


Figure 2.
Product portfolio from the ladle to the mould.

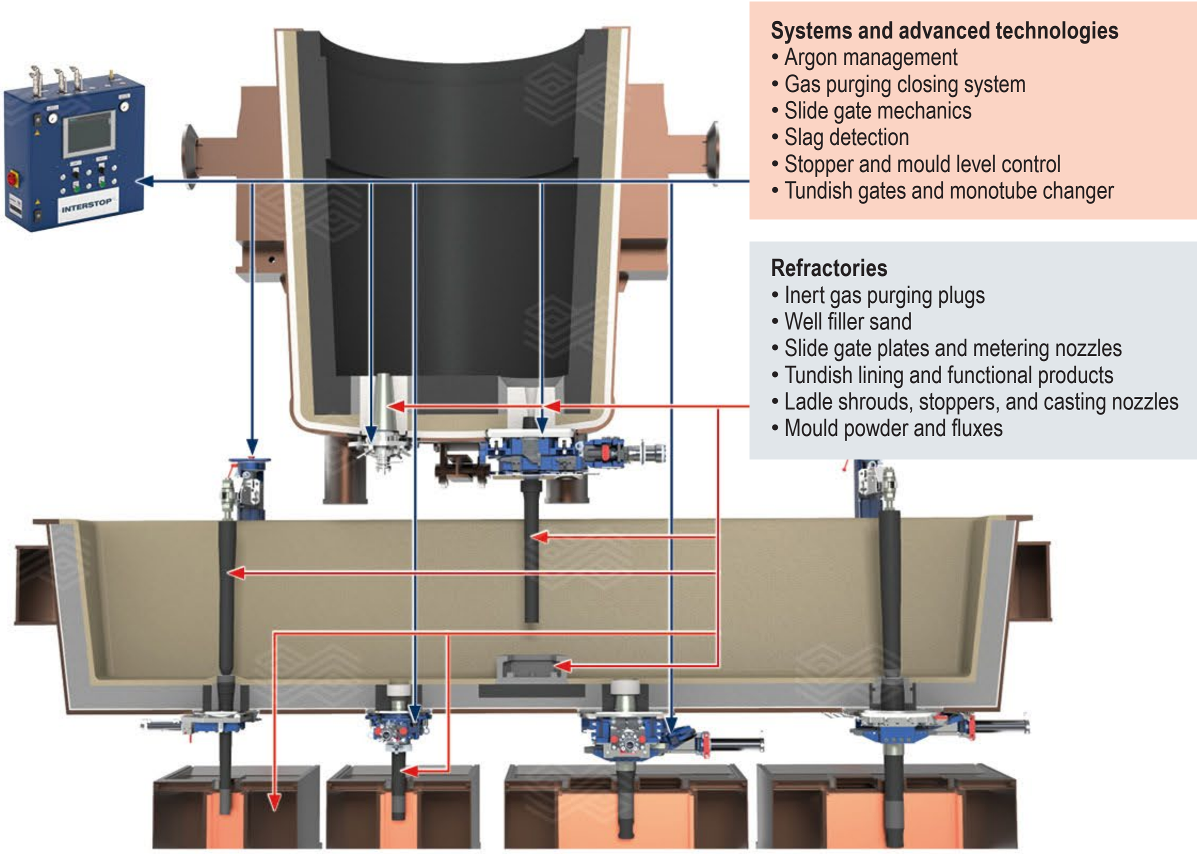
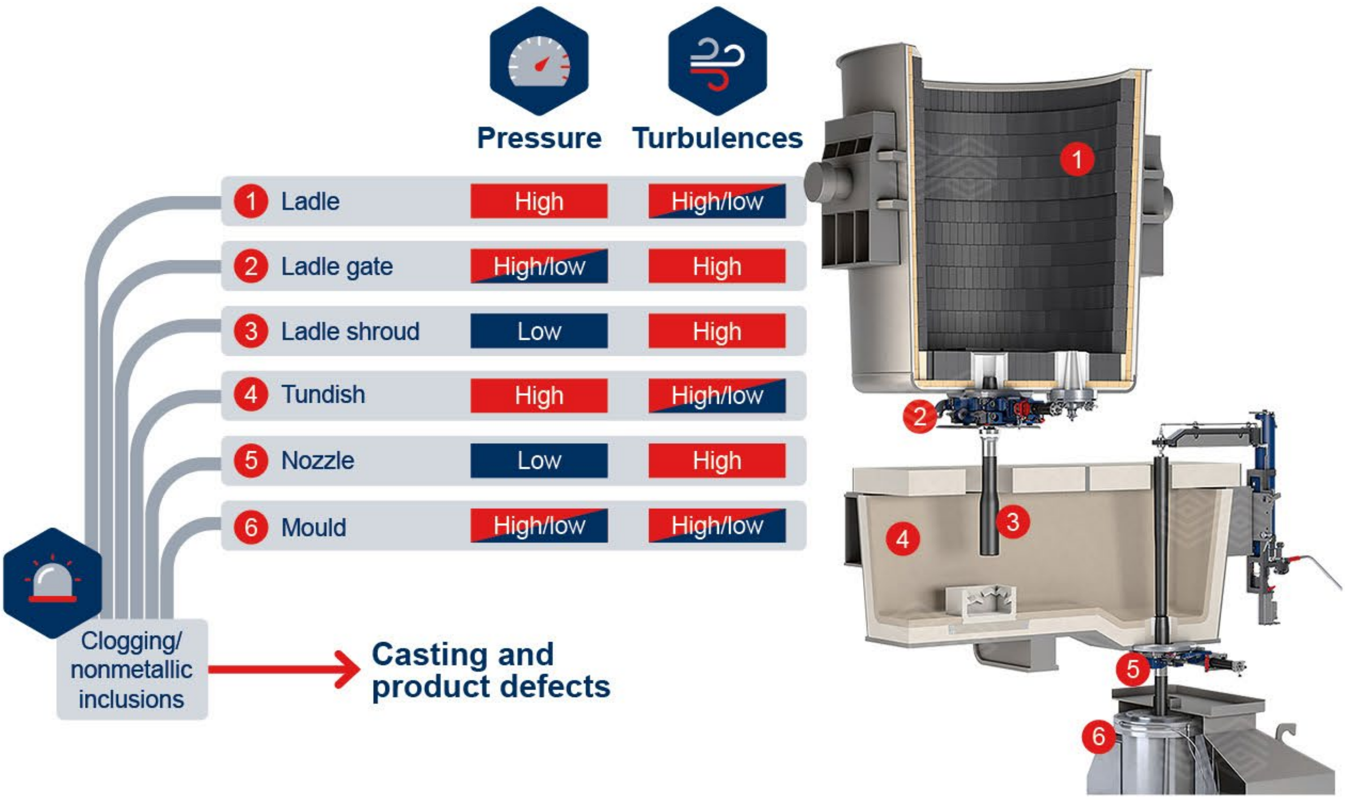


Figure 3.
Potential sources of steel contamination.



Ladle Operation

A key to clean steel casting is steel cleanliness in the ladle, which requires the temperature and nonmetallic inclusion load in the melt to be accurately controlled and every ladle in the casting sequence to be as reproducible as possible. This can be effectively achieved using inert gas purging with hybrid plugs [3], a technology that generates both the high gas flow rates required for rapid metallurgical treatment and melt homogenisation as well as fine bubbling for inclusion flotation while avoiding reoxidation at the meniscus. Using water modelling experiments it has been possible to determine the relationship between gas flow rates and bubble size for different inert gas purging plugs and visualise the high number of bubbles generated by hybrid plugs (Figure 4).

The main features and benefits of hybrid plugs are:

- Multicomponent plug combining random and directional porosity.
- Excellent flow rate adjustability.
- High volume of fine bubbles at low flow rates.
- 100% opening rate.
- Integrated safety indicator.
- Low service costs.
- Supports continuous and discontinuous operations as well as high ladle bottom lifetimes.

An important challenge with inert gas purging is to control the bubble size distribution at low argon flow rates. Especially at the beginning of the gas purging process, a dense slag cover on the steel bath surface makes it very difficult for the operator to define the correct flow rate. Furthermore, if gas purging is excessive the formation of an open eye on the steel surface can create issues with unwanted reoxidation and the formation of nonmetallic inclusions.

To address this issue, RHI Magnesita has been investigating the vibrational patterns of different inert gas plugs as an approach to characterise gas purging behaviour. This is achieved by installing an acceleration sensor on the outer gas pipe of the purging plug and online analysis of the vibration signals using special fast Fourier transformation algorithms to generate the relative bubble size (i.e., bubble index) (Figure 5). The aim of this technology is that the bubble index will indicate to the operator the actual purging

Figure 4.

Hybrid purging plug performance visualised using water modelling experiments. (a) relationship between bubble size, bubble number, and gas flow rate and (b) comparison of a hybrid and slot plug.

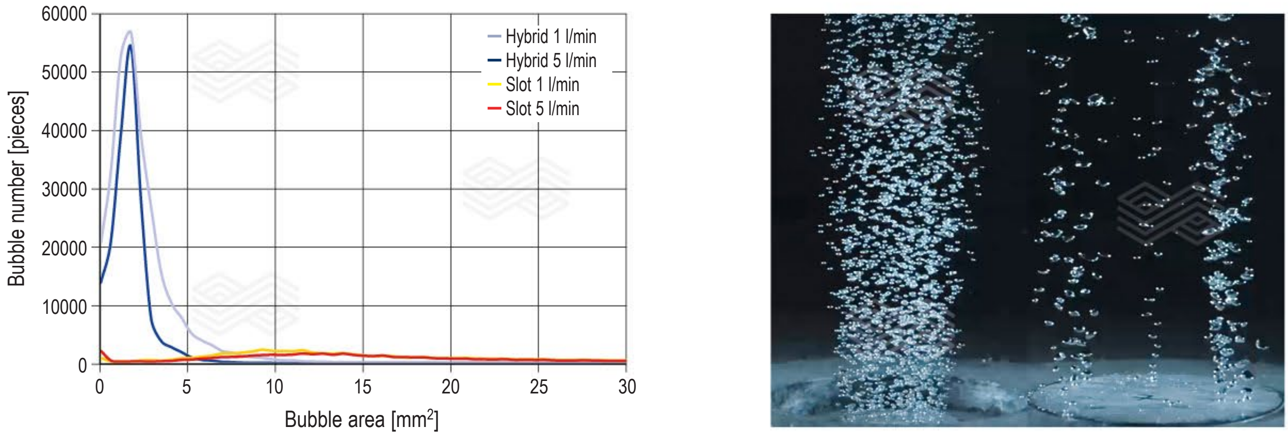
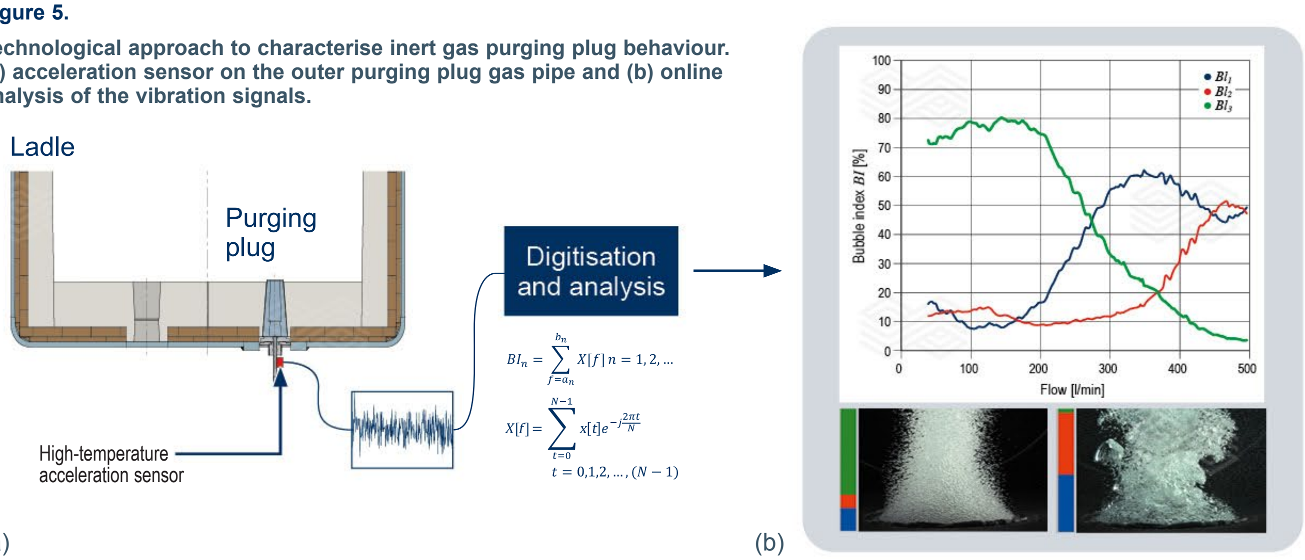


Figure 5.

Technological approach to characterise inert gas purging plug behaviour. (a) acceleration sensor on the outer purging plug gas pipe and (b) online analysis of the vibration signals.



performance, even when the liquid steel surface is not visible during the purging process [4]. This technology will help to improve the consistency of inert gas purging control, also under different purging plug wear conditions. The main characteristics of this technology include:

- An acceleration sensor mounted on the purging plug gas pipe.
- The signal is digitised and converted into a frequency spectrum.
- An algorithm transforms the frequency spectrum into a bubble index.
- The relative bubble size distribution can be visualised.
- Purging plug performance can be optimised.

Ladle to Tundish Transfer

With steel transfer from the ladle to the tundish, a batch operation becomes a continuous process. To maintain an almost constant steel level in the tundish, a slide gate mounted on the ladle bottom controls the quantity of liquid steel flowing through the ladle shroud into the tundish. Due to the negative pressure below the throttling of the ladle gate system, a strong pressure drop occurs in the steel stream [5].

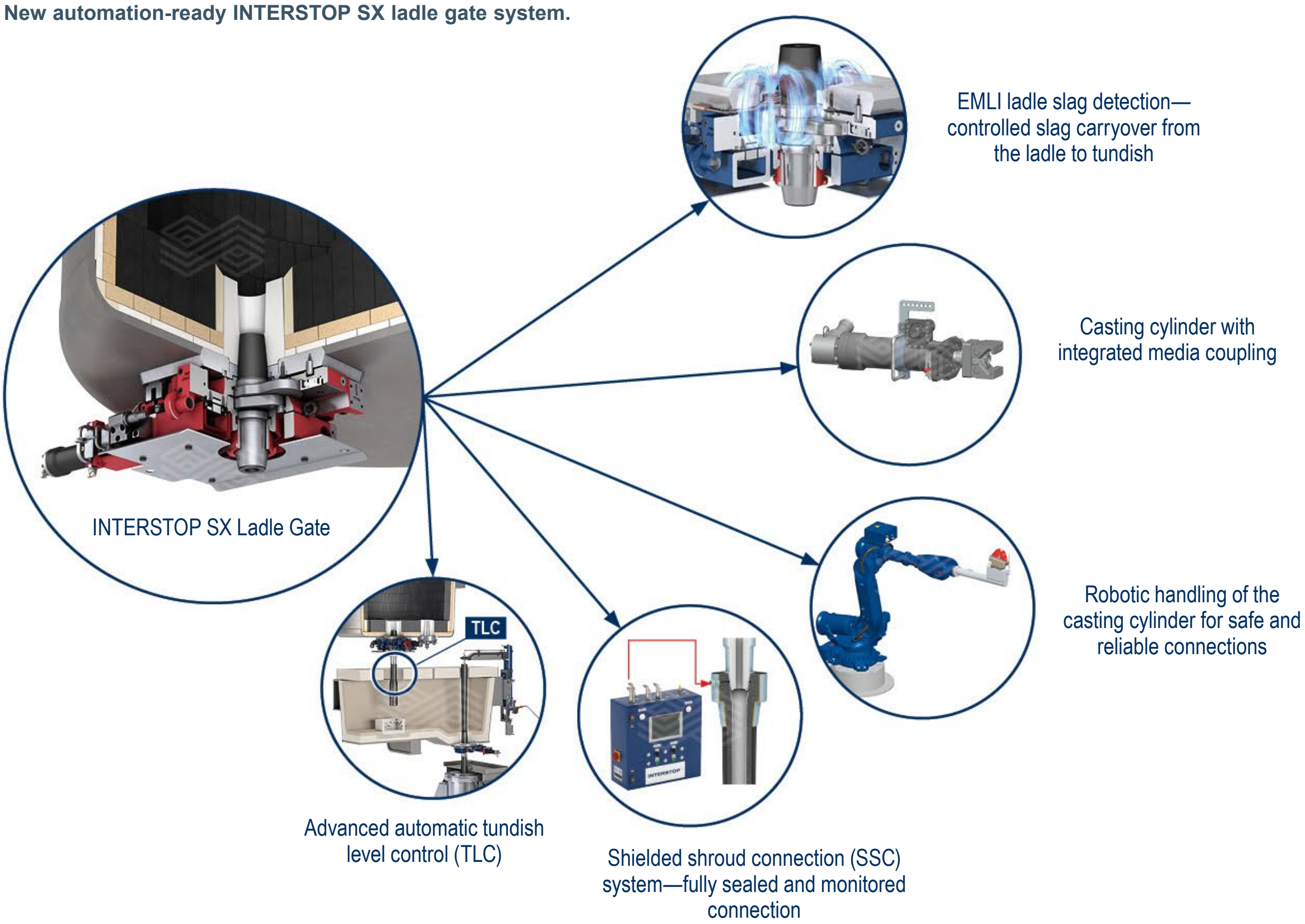
A typical setup for the new automation-ready gate is shown in Figure 6 [6,7]. This INTERSTOP SX ladle gate system provides not only excellent operational performance, but an improved cost benefit compared to other gate systems. Furthermore, the system can be upgraded at any time with various technical features including:

- Electromagnetic slag detection system (EMLI) to minimise ladle slag carryover.
- Casting cylinder with automation-ready media couplers.
- Robotic handling system for safe ladle gate operations.
- Shielded shroud connection (SSC) systems to minimise air aspiration into the casting channel.
- Advanced automatic tundish level control (TLC) for smooth operation.

Furthermore, as refractories such as ladle slide gate plates must resist extremely high thermal shocks due to cold starts, RHI Magnesita offers a wide range of high-performance grades that are appropriate for different gate systems and plate sizes [8].

The main purpose of a ladle shroud is to avoid steel oxidation during its transfer from the ladle into the tundish. High turbulences in the casting channel, which are created by high ferrostatic pressure and severe slide gate throttling practise, require special refractory solutions. In order to avoid erosion and potential holing in the steel impingement area of the ladle shroud, a high erosion resistant inner liner is required. Such a reinforcement liner concept is often necessary for big slab caster reverse taper or bell shrouds.

Figure 6.
New automation-ready INTERSTOP SX ladle gate system.



When opening the steel flow with a new ladle, an immersed opening ensures avoiding reoxidation of the steel stream. In addition, it reduces the risk of tundish cover powder emulsifiaction. Such shrouds, due to their longer shape and bigger exit diameters (to avoid blow-back), are approximately 50% heavier than standard shrouds (Figure 7).

Thermomechanical stresses, which can result from the ladle shroud contact to the collector nozzle, need special refractories reinforced with metal cans to ensure safe and reliable operation with minimal nitrogen pickup [9]. Typical shrouds with a reinforced throat and inner liner are shown in Figure 7. The key features and benefits of high-performance ladle shrouds include:

Figure 7.
High-performance ladle shrouds.

- Immersed opening possible for bell and reverse taper shrouds.
- Very good thermal shock resistance for cold starts.
- Resistance against high manipulator upthrust forces.
- Metal can support.
- Argon shielding possible.
- Less transition slabs.
- Outstanding oxidation resistance in the throat for oxygen lancing.
- Wear-resistant liner.
- Slagline reinforcement possible.

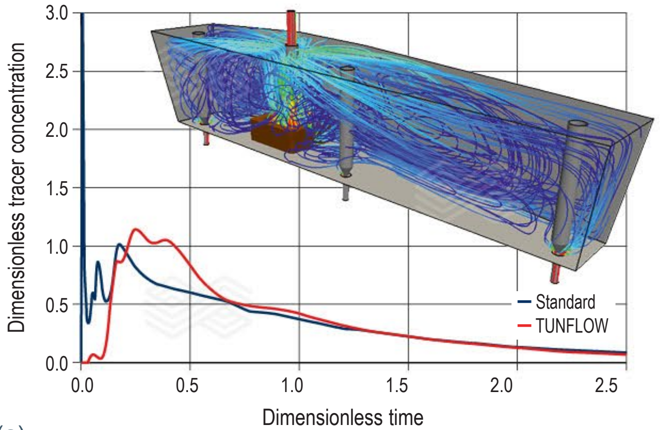
In addition to the above-mentioned topics, sealing and inert gas shielding at the ladle shroud connection to the collector nozzle are important [10]. Although different design solutions for sealing and shielding are available to ensure stable and safe operation, during process improvements sealing must be regarded as the first priority and shielding as the second.

Tundish Operation

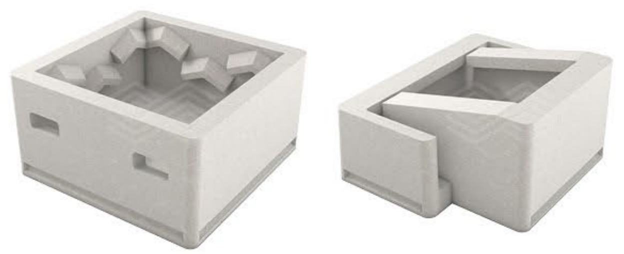
When steel flows through the ladle shroud into the tundish, the turbulent kinetic energy needs to be dissipated to avoid refractory wear and the direction of steel flow must be optimised to improve residence time and inclusion flotation. Furthermore, the steel flow needs to be controlled to feed all strands with the same steel quality and temperature. Simulation tools like water modelling in combination with computational fluid dynamics enable different TUNFLOW impact pots to be designed for the required tundish geometry and throughput (Figure 8). These shapes need to be customised to achieve maximum performance and the lowest conversion costs during tundish operation [11,12]. In summary, the advantages of TUNFLOW impact pots are:

- Designed to the customer's requirements using state-of-the-art simulation technologies.
- Barriers to eliminate kinetic energy.
- Design to promote plug flow.
- Support the flotation of nonmetallic inclusions by enhancing residence time and flow direction.
- High anti-splash properties.
- Reduced slag emulsification.
- Less surface turbulence and reoxidation.
- Cold start capabilities.

Figure 8.
(a) computational fluid dynamics to examine tracer concentration in the tundish and (b) TUNFLOW designs.



(a)



(b)

Additional refractory advances in the tundish area include energy-saving lining technologies that reduce the CO_2 footprint due to a decreased gas consumption for heat-up procedures, such as sol-bonded mixes for the permanent lining and cold-setting (i.e., self-hardening) wear lining mixes (see page 68). Besides the environmental and energy saving benefits, the self-hardening mixes (e.g., ANKERTUN SH) result in faster relining and better availability of the tundish fleet [13,14].

In addition to TUNFLOW impact pots and tundish lining using energy-saving mixes, thermodynamic simulations (e.g., FactSage) can be used to optimise steel/refractory/tundish slag interactions for minimum steel contamination. As a result of combining all these approaches, the overall cost per tonne of cast steel can be reduced.

INTERSTOP's new slide gate systems for tundish operation incorporate sealed housing and inert gas purging to avoid air ingress at the junction between the plates. This development not only results in improved steel cleanliness, less clogging, and increased sequence length, but also widens the product portfolio [15]. Furthermore, for slab casters an integrated monotube changer provides additional safety and the possibility for long sequence casting. Very important features to achieve stable mould level performance are (Figure 9):

- Accurate regulation of the cylinder and slide gate.
- Advanced mould level control system and sensors.
- Controlled argon feeding for the gate system and casting channel.
- Wear-resistant refractory shrouding system.

All these components can be assembled according to the special needs and requirements.

Argon Purged Stoppers for Slab Casting

Argon purged stoppers are widely used for casting Al-killed steel grades to minimise nonmetallic inclusions precipitating on the casting nozzle inner surface. However, as nonhomogeneous argon bubble injection has been shown to result in severe mould level fluctuations and contribute to surface defects, the Slot Hole Plug (SHP) stopper nose design was developed (Figure 10) [16,17]. In addition to reducing sliver defects on the slab surface, the SHP stopper technology results in a stable gas feed and fine bubble distribution to capture inclusions whenever they flow into the casting channel. This even distribution of fine bubbles reduces mould level perturbations caused by unwanted bubble bursting effects on the steel meniscus in the mould and flow pattern changes from bubbly- to slug-flow can also be minimised with improved argon purging strategies. Ultra low carbon (ULC) steel grades have been shown to benefit the most from using the SHP argon stopper technology.

Figure 9.
Sealed tundish slide gates for billet, bloom, and slab casters.

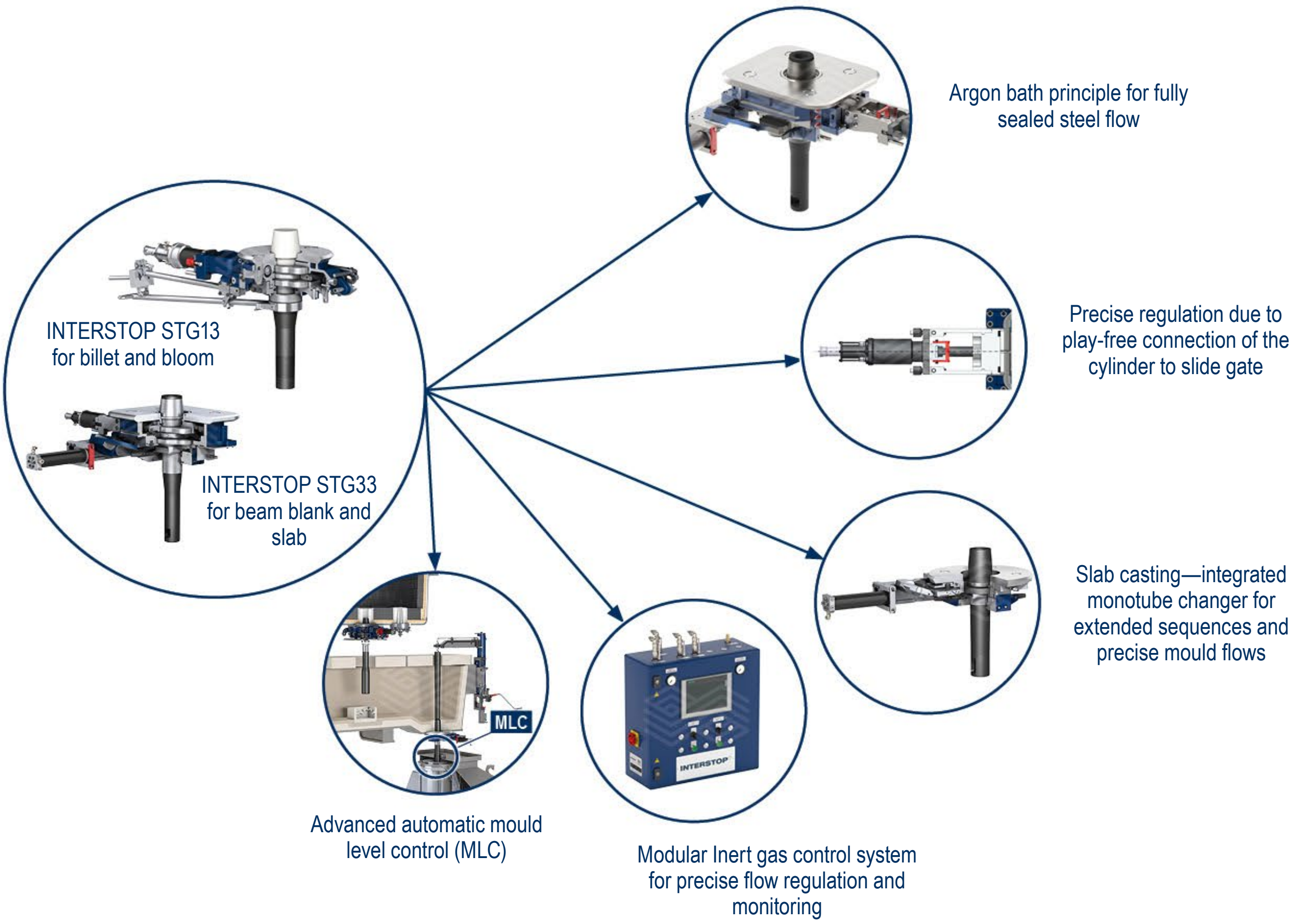
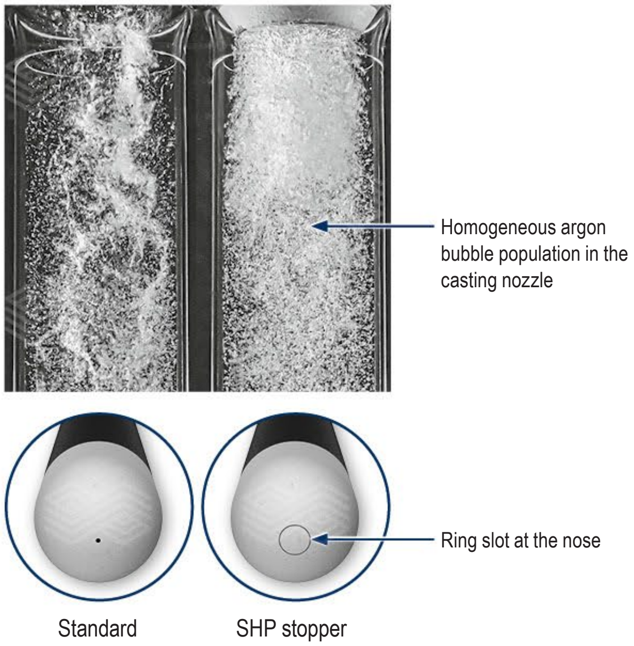


Figure 10.
Comparison of a standard and SHP stopper for argon purging.



High-Performance Refractories for Anticlogging

In addition to the aforementioned high-performance systems and refractories available from RHI Magnesita for clean steel applications, clogging in the casting channel can be further minimised by:

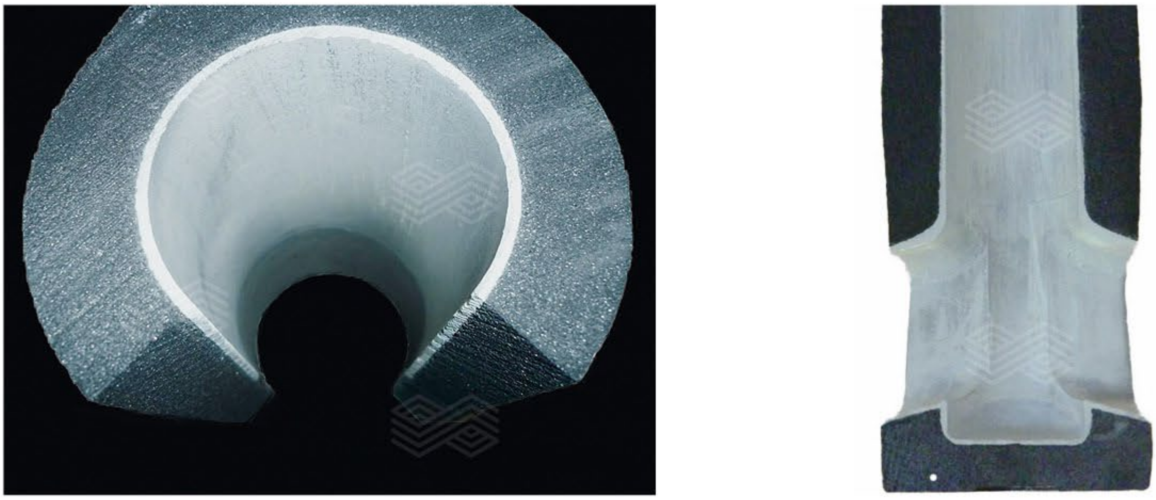
- Combining argon purged refractories. For example, using the direct purging mononozzle technology in combination with an argon purged stopper (Figure 11) [18].
- Incorporating special liners with anticlogging properties in the inner bore of casting nozzles (Figure 12) [19,20].

Conclusion

The formation of nonmetallic inclusions and refractory clogging during steelmaking have detrimental effects on steel cleanliness and conversion costs. Therefore, RHI Magnesita has developed a comprehensive portfolio of flow control systems and refractories for clean steel casting. Using state-of-the-art equipment, a range of products has been designed showing excellent thermomechanical properties and corrosion resistance required for demanding

Figure 11.
(a) direct purging mononozzle and (b) combining an argon purged stopper and the direct purging mononozzle technology.

Figure 12.
Cut products showing an anticloggging inner liner in the bore.



applications. In addition, optimising numerous operational parameters in the continuous casting process can also contribute to steel cleanliness and less clogging, such as improving the refractory preheat cycle, product installation, casting nozzle design [21–23], and sealing the gas feeding lines [10]. Overall, an optimum result can only be achieved by trying to address all influencing factors summarised in this article [24]. Factfinding plays a key role in identifying the highest potentials for improvement in the process chain from the ladle to the mould. Furthermore, customising solutions available in RHI Magnesita's portfolio can contribute to metallurgical and process advances, leading to a more efficient operation that includes energy savings and a reduced CO_2 footprint.

References

[1] https://www.sidenor.com/wp-content/uploads/2017/06/SID_WHITEPAPER_ACEROS_LIMPIOS_EN.pdf

[2] Smith, R. and Ordosch, A. Steel CO_2 Dashboard. October 2020. CRU International Ltd., London, UK.

[3] Trummer, B., Fellner, W., Viertauer, A., Kneis, L. and Hackl, G. A Water Modelling Comparison of Hybrid Plug, Slot Plug and Porous Plug Designs. *RHI Bulletin*. 2016, 1, 35–38.

[4] Trummer, B., Manhart, C. and Fellner, W. Vibrational Determination of Gas Purging Regime and Efficiency in a Water Model and Validation by a High-Speed Camera. *Bulletin*. 2020, 50–54.

[5] Hackl, G., Fellner, W., Heinrich, H. and Bühlmann, R. New Slide Gate Water Model Facility. *RHI Bulletin*. 2017, 1, 60–63.

[6] Ehrengruber, R., Baumgartner, G., Steins, A. and Renggli, R. Latest INTERSTOP Ladle and Tundish Systems Ready for Robotic Handling. *Bulletin*. 2021, 48–52.

[7] Ehrengruber, R., Bühlmann, R., Schmidt, V. and Persson, M. Influence of the Trends Robotics and Digitalisation on Ladle Slide Gate Development. *China Refractories*. 2021. 30, 30–34.

[8] Müller, M.A., Sherriff, R. and Wiesel, M. Development of Slide Gate Refractories Based on the Investigation of Wear Mechanisms. *RHI Bulletin*. 2007, 1, 39–42.

[9] Pinto, J., Freire, R., Resende, R. and Martins, D. Ladle Shroud Design Optimisation through Numerical Modelling. *Bulletin*. 2019, 46–50.

[10] Ehrengruber, R., Excellence in Inert Gas Control Systems for the Steel Industry. *RHI Bulletin*. 2015, 1, 7–15.

[11] Arth, G., Meurer, D., Kappel, M., Loop, P. and Petritz, B. Tundish Technology and Processes: Ladle to Mould Systems and Solutions (Part III). *Bulletin*. 2018, 64–70.

[12] Resende, A., Lukesch, G., Hackl, G. and Meurer, D. Tundish Refractory Design Optimisation Through Mathematical and Physical Modelling. *Bulletin*. 2021, 1, 60–65.

[13] Kirschen, M., Badr, K., Cappel, J. and Drescher, A. Intelligent Refractory Systems: A Cost Effective Method to Reduce Energy Consumption and CO_2 Emissions in Steelmaking. *RHI Bulletin*. 2010, 2, 43–49.

[14] Sorger, R. and Petritz, B. New Cold-Setting Mixes for Tundish Wear Linings. *RHI Bulletin*. 2011, 1, 54–58.

[15] Heinrich, B., Cousin, J-D., Bühlmann, R. and Ehrengruber, R. New INTERSTOP Sealed Tundish Gate for Billet and Bloom Casting, *Bulletin*. 2022, 29–33.

[16] Nitzl, G., Liu, X., Liu, Q., Shen, J. and Tang, Y. New Argon Stopper Technology for Slab Casting. *China Refractories*. 2021, 30, 41–44.

[17] Krumpel, G., Fuchs, R., Posch, W., Michelitsch, A. and Hackl, G. Optimized Argon Supply from Tundish to Mold using the SHP stopper. Proceedings of METEC and 2nd ESTAD, Düsseldorf, Germany, June 15–19, 2015.

[18] Seitz, P., Nitzl, G., Fauhl, M. and Botvinikova, O. New Direct Purging NC Technology for Slab Casting. *Bulletin*. 2021, 54–58.

[19] Seitz, P., Tang, Y. and Nitzl, G. Refractory Tubes with Innovative Liner Technology for Flow Control and Clean Steel Applications. *Bulletin*. 2020, 42–48.

[20] Dösinger, H., McFarlane, C., Nitzl, G., Tang, Y. and Hackl, G. Anticlogging Solutions for Isostatically Pressed Submerged Nozzles. *RHI Bulletin*. 2015, 1, 84–87.

[21] Hackl, G., Tang, Y., Nitzl, G., Chalmers, D., Dorricott, J. and Heaslip, L. Design Optimization of Submerged Entry Nozzles Using Simulation Technology. *RHI Bulletin*. 2014, 1, 47–53.

[22] Hackl, G., Tang, Y., Nitzl, G., Schurmann, D., Willers, B. and Eckert, S. GYRONOZZLE – An Innovative Submerged Entry Nozzle Design for Billet and Bloom Casting. *Bulletin*. 2019, 52–57.

[23] Hackl, G., Nitzl, G., Tang, Y., Eglsäer, C. and Krumpel, G. Novel Isostatically Pressed Products for the Continuous Casting Process. *RHI Bulletin*. 2015, 1, 78–83.

[24] Raidl, G. and Cappel, J. The Basics of Clean Steel in Continuous Casting. ARCS-13, Ispat Bhawan, SAIL, Ranchi, India, June 26–28, 2013.

Authors

Rainer Neuböck, RHI Magnesita, Leoben, Austria.
Gerald Nitzl, RHI Magnesita, Vienna, Austria.
Christoph Eglsäer, RHI Magnesita, Vienna, Austria.
Reinhard Ehrengruber, RHI Magnesita Switzerland AG, Hünenberg, Switzerland.
Corresponding author: Christoph Eglsäer, Christoph.Eglsaeer@rhimagnesita.com

Bulletin

The Journal of Refractory Innovations

2024

Published by RHI Magnesita GmbH, Vienna, Austria
Chief Editor Thomas Prietl
Executive Editors Celio Carvalho Cavalcante, Thomas Drnek, Christoph Eglsäer, Celso Freitas, Alexander Leitner, Ravikumar Periyasamy, Stefan Postrach, Peter Steinkellner, Karl-Michael Zettl
Raw Materials Expert Matheus Naves Moraes
Technical Proofreader Clare McFarlane
Lingual Proofreader Clare McFarlane
Project Manager Michaela Hall
Design and Typesetting Universal Druckerei GmbH, Leoben, Austria

Contact Michaela Hall
RHI Magnesita GmbH, Technology Center
Magnesitstrasse 2
8700 Leoben, Austria

E-mail bulletin@rhimagnesita.com
Phone +43 50213 5300
Website rhimagnesita.com
LinkedIn https://www.linkedin.com/company/rhi-magnesita

Cover picture: The image depicts the lower section of a RH degasser, a secondary metallurgical unit used in steel plants. In the RH degassing process, snorkels are submerged into liquid steel contained in the casting ladle. Argon gas is purged through the inlet snorkel, creating a suction effect that draws liquid steel into the lower vessel of the RH degasser, where a vacuum is applied. The steel treated in the lower vessel flows back to the ladle through the outlet snorkel, creating a continuous steel circulation between the ladle and the RH degasser. The strong negative pressure (vacuum) within the RH degasser facilitates various metallurgical processes that enhance steel quality, with the key process steps including degassing, decarburisation, deoxidation, and alloying under vacuum. Rail steel, flat steel for the automotive industry, and steel plates for shipbuilding are just a few examples of products that benefit from the RH degasser. Prefabricated snorkels, which RHI MAGNESITA manufactures ready for use and delivers to our globally operating customers, are essential components of the RH degasser.