

IMPROVING THE DESIGN OF A 6-STRAND TUNDISH FOR PRODUCTION OF CLEAN STEELS THROUGH VIRTUAL PROTOTYPING AND SIMULATIONS

¹Krishnakumar KRISHNAPISHARODY, ¹Andreas MÜLLER, ¹Christian BRUCH

¹Research and Development, Saarstahl AG, Völklingen, Germany, EU,
Kumar.Krishnapisharody@saarstahl.com

<https://doi.org/10.37904/metal.2026.5235>

Abstract

The European steel industry is facing transformational changes that will affect metallurgical quality, including steel cleanliness. In the face of this, digital simulation and virtual engineering methods are being increasingly employed in the steel industry to test and optimize process and equipment designs quickly and accurately. The present work deals with design optimization to improve the steel flow conditions in a 6-strand tundish of a billet caster for enhanced cleanliness through virtual prototyping using Computational Fluid Dynamic (CFD) simulations and subsequent plant trials of the most promising designs. A 3D Reynolds-Averaged Navier-Stokes approach using the realizable k- ϵ model of turbulence together with a two-phase model of steel-argon flows was employed to simulate the tundish flow and to propose design modifications. Several virtual prototypes with additional flow modifiers were evaluated to predict performance and optimize the design configurations. A pair of appropriately sized extra flow diversion elements, placed at 100 mm from the weirs on either side of the tundish center, was found to give the best results. This configuration minimizes steel short-circuiting from the in-gate region into the tundish trough, reduces turbulence near the bath surface, and promotes slow plug-like flow towards the tundish ends, thereby improving the conditions for the removal of non-metallic inclusions. The effectiveness of the optimized design was confirmed by inclusion-characterization results obtained from plant trials.

Keywords: Tundish flow, clean steel, continuous casting, simulation

1. INTRODUCTION

Saarstahl AG, a leading European manufacturer of long steel products, produces billets/blooms through the continuous casting technique, a process in which molten steel is solidified into semi-finished strands in a continuous manner. The tundish is a critical refractory vessel in this process. It distributes steel from the ladle to the individual casting strands thus allowing for ladle changes during the casting process and enabling continuous operations across multiple steel heats [1]. It is also the last unit in which the final treatment of the liquid steel can be performed before it reaches the mold. The stability of the casting process and the metallurgical quality and cleanliness of the final product are influenced primarily by the flow dynamics of molten steel in the tundish prior to casting [1,2]. As purity requirements for high-quality steel grades – such as tire cord or spring steels – have become increasingly stringent, greater attention has been paid to the tundish and in particular, the flow conditions within it.

In this regard, different ideas were developed internally to further minimize the steel flow velocities at certain critical locations inside the tundish and to optimize the flow directions in the tundish trough. This was intended to improve the removal conditions for non-metallic inclusions, reduce the risk of tundish-slag entrainment, and minimize inclusion transfer into the inner strands thereby enhancing the degree of cleanliness.

The present work aimed to optimize the flow-control elements of a six-strand tundish using CFD-based virtual prototyping. Several configurations were evaluated, and the most promising design was subsequently validated in plant trials by optical characterization of non-metallic inclusions.

2. NUMERICAL SIMULATIONS

The object investigated is a T-shaped 6-strand continuous casting tundish at Saarlust AG used for the production of clean steel grades. The tundish has a dam–weir pair on either side of the center and is symmetrical relative to the transverse plane. The billet tundish as shown in **Figure 1** has a nominal capacity of 26 t and supplies six 150 mm × 150 mm strands at casting speeds exceeding 2.0 m/min. Liquid steel is supplied from the ladle above the tundish through a free-falling pouring stream in an inert gas atmosphere. Steel is supplied to the mold through submerged entry nozzles (SEN), while the mold level is controlled by stopper rods.

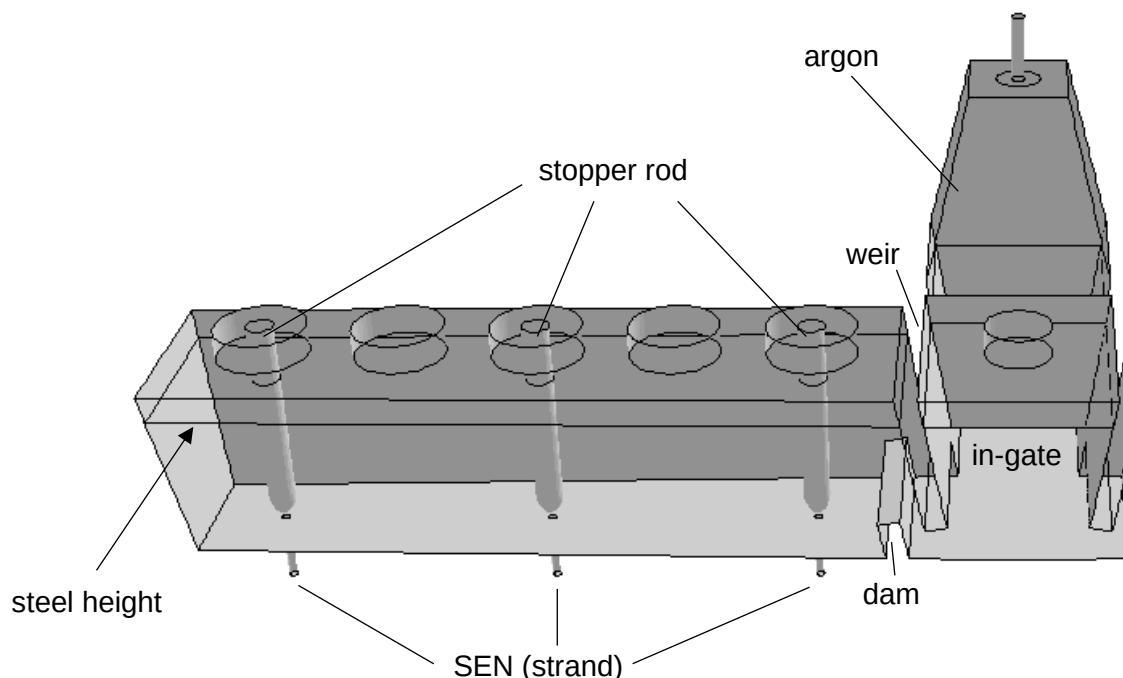


Figure 1 Schematic representation of one half of the tundish, showing strands 4–6 at Saarlust AG

The numerical simulations of fluid flows inside the tundish in various configurations were performed using the finite-volume-based commercial CFD software ANSYS FLUENT 6.3.26. The steel flow was modeled using the Reynolds Averaged Navier-Stokes (RANS) equations in a transient manner, which is a standard approach for this type of flow [3]. As the tundish contains an inert argon atmosphere, a Volume-of-Fluid (VoF) model was further employed to describe the steel-argon interface. Turbulence was handled using the realizable k - ϵ model with standard wall functions to model the near-wall regions [4]. This form of turbulence modeling is robust and provides acceptable accuracy at a reasonable computational cost for such wall-bounded internal flows. The details of the numerical models and their implementation can be found here [5]. All the computations were made under the assumption of incompressible flow and isothermal conditions at the temperature of 1550 °C. The calculations were generally performed for a period of 1 minute in real-time until the flow reached a quasi-steady state. .

The necessary geometries and computational meshes of various tundish configurations were created as virtual prototypes with the Gambit preprocessor of the FLUENT package by means of a scripting procedure. The

computational domain of a typical tundish configuration consists of block-structured grid with approximately 800,000 cells.

3. RESULTS AND DISCUSSION

3.1 Tundish in standard configuration

First, numerical simulations were performed to assess the state of flow in detail inside the tundish in its original configuration with weir and dam as shown in **Figure 1**. The obtained results show the following general characteristics: fresh steel coming into the tundish volume from the in-gate region passes through the channel between the weir and dam, flows upwards above the dam, turns horizontally at the bath surface and spreads into the interior of the trough. Thereafter it exhibits a slow plug-flow like behavior in the longitudinal direction up to the ends in both arms of the tundish where the velocities are generally less than 0.05 m/s. These effects are shown in **Figure 2** where the velocity field (contours and vectors) is presented on a vertical plane passing through the middle of the tundish trough and the stopper rods. The three-dimensional representation of this steel movement is further shown in **Figure 3** which depicts the velocity fields on three horizontal planes at the bottom, middle and top of the tundish, respectively. The same effects can be identified in this figure also.

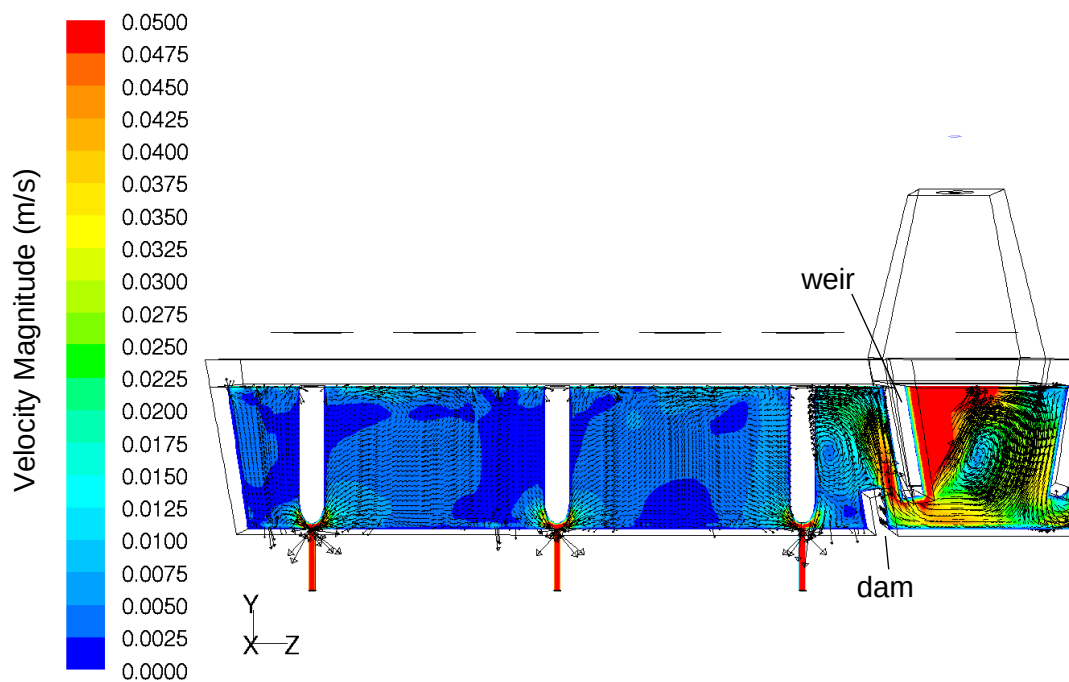


Figure 2 Velocity field in one half of the tundish on a vertical longitudinal mid-plane in the original configuration

Although the flow pattern in the tundish in this configuration as described above has many desirable features like plug-like behavior with relatively low velocities and consequently, low turbulence levels, some non-idealities and undesirable effects were also noticed which may negatively impact the separation and removal of inclusions in the trough. These include: (i) the higher upward flow velocities between the dam and weir (**Figure 2**) – which may lead to larger bath surface disturbances directly above the dam and (ii) short-circuiting of the steel flow under the weir, where a part of the incoming steel stream flows directly under the side of the weir near the in-gate, leading to stronger upward flows and consequently larger bath surface velocities behind the side of the weir close to the in-gate. This is shown in **Figure 3**. Due to this, the short-circuiting stream will not penetrate deep into the tundish volume between the weirs and recirculate within the central tundish region,

diminishing the chance of inclusion separation through slag contact in this region. Further simulations were carried out with the aim of optimizing the flow in these areas to address these deficiencies.

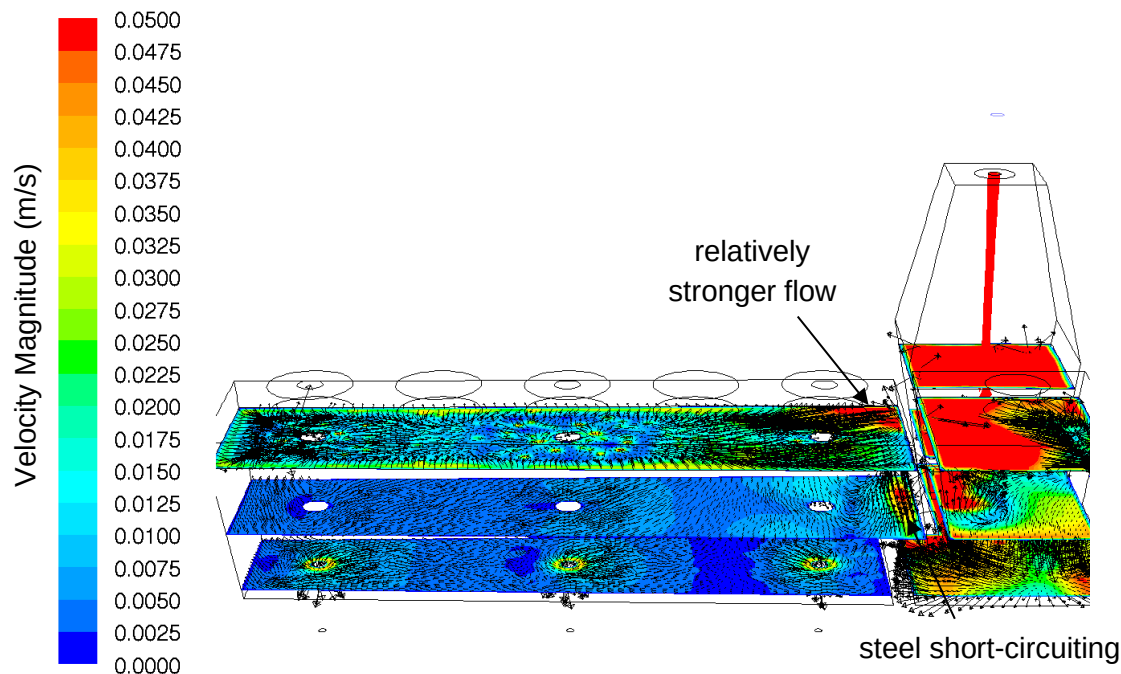


Figure 3 Velocity fields on three horizontal planes in one half of the tundish in the original configuration

3.2 Alternative design variants

As noted in Introduction, several design concepts were explored through simulations on a variety of tundish prototypes with different configurations of flow modifiers. There were variants with (i) increased heights of the in-gate region keeping the same cross-section thereby limiting the in-gate passage laterally; (ii) chamfers on the facing edges of the dam and weir to broaden the “effective” passage between them; and (iii) an additional pair of inner dams before the weirs in the middle volume of the tundish. Of these, variants in category (i) did not lead to the desired result as both the negative effects mentioned earlier (short-circuiting and relatively stronger upward flows between dam and weir) were not significantly reduced. In the case of category (ii), the upward flow velocities between dam and weir were reduced, however the short-circuiting remained. The variant with an additional pair of inner dams was able to mitigate both the negative effects to a significant extent, as will be described in the next section. In the optimized configuration, the original dam and weir are shifted 100 mm outwards to make space for an additional dam in the middle section of the tundish, 100 mm away from the weir.

3.3 Tundish in “double-dam-weir” configuration

The results of the CFD simulations in this modified “double-dam-weir” configuration revealed that the general flow patterns inside the tundish trough (outside of the regions with dams and weirs) were qualitatively similar to those obtained in the original configuration. In this case, the fluid flow is slow and predominantly unidirectional towards the ends of both arms of the tundish, with velocities typically below 0.05 m/s. The results are shown in **Figures 4 and 5**, where the velocity fields on different vertical and horizontal planes inside the “double-dam-weir” configuration are presented, as in Section 3.1.

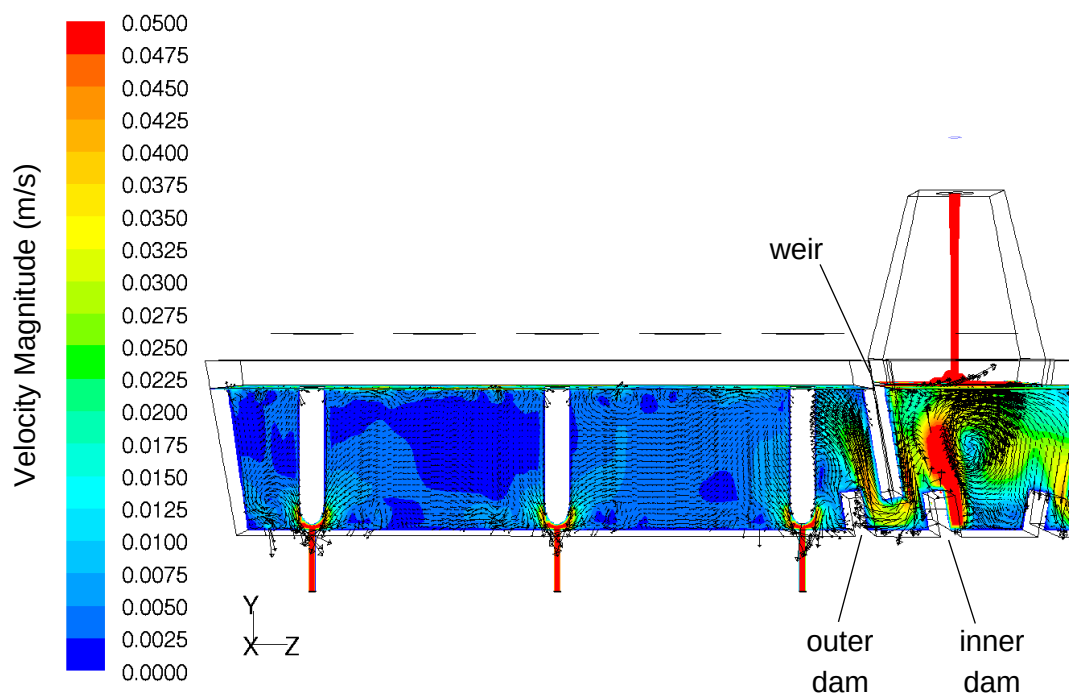


Figure 4 Velocity field on a vertical longitudinal mid-plane in one half of the tundish in the “double-dam-weir” configuration

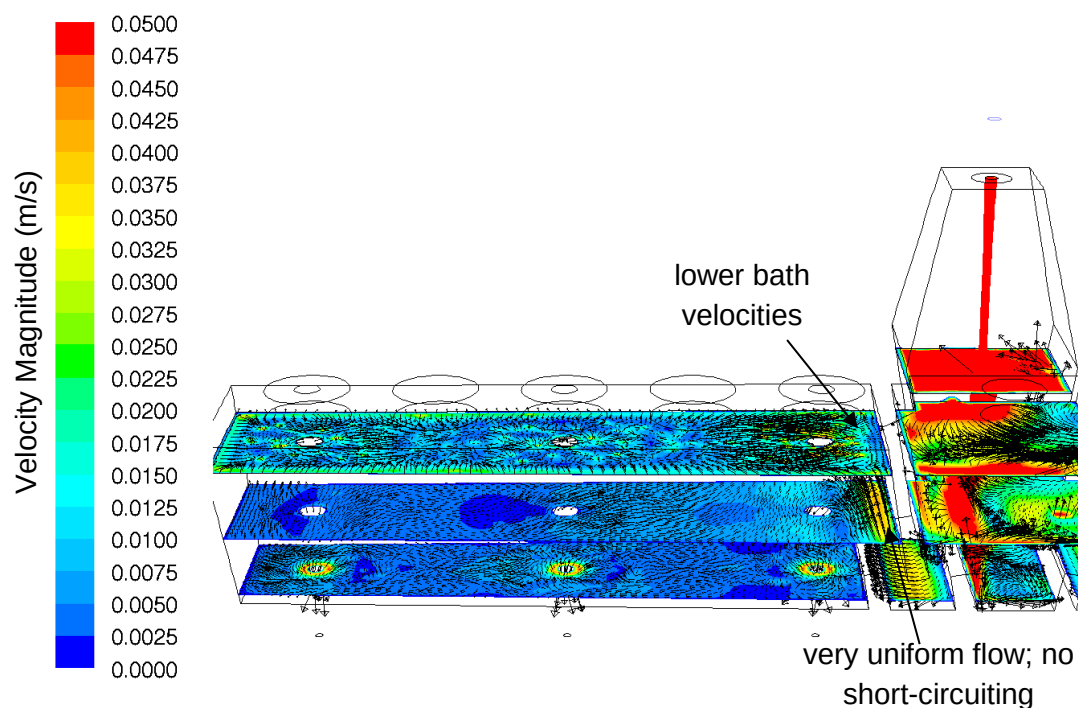


Figure 5 Velocity fields on three horizontal planes in one half of the tundish in the “double-dam-weir” configuration

The improvements in flow at critical locations in the “double-dam-weir” configuration are evident from **Figures 4 and 5**. It can be seen that, due to the inner dam, the short-circuiting of incoming steel under the weir is largely suppressed leading to the benefits: (i) a relatively calm and very uniform flow over the tundish cross-section

between the weir and the outer dam with substantially lower velocities (**Figure 4**); and (ii) relatively lower steel bath velocities directly above the outer dam (**Figure 5**). These benefits contribute to achieving a slow uniform flow under the bath surface with lower turbulence up to the tundish extremities. The incoming steel stream can also penetrate deeper into the volume between the inner dams and form a circulation loop between the weirs. These effects are expected to provide enhanced conditions for the removal of non-metallic inclusions.

3.4 Plant trials and metallurgical investigations of steel cleanliness

To test the effectiveness of the optimized tundish design, plant trials were carried out. Two high-quality and inclusion-sensitive Si-Mn-killed steel grades A and B, differing mostly in their carbon content, were chosen and eight casting sequences of typically five to eight heats were produced employing the improved tundish design, i.e. a 6-strand tundish in “double-dam-weir” configuration (see **Figure 4**). Of these, 33 heats were then rolled using the standard process for the respective steel grade and subsequently the micro-cleanliness of each heat was analyzed by optical microscopy of typically 20 to 30 wire rod samples. An internal inclusion index based on counting size-class-dependent penalty points for critical non-metallic inclusions larger than 5 μm (similar to DIN 50602 for non-metallic inclusions [6]) was then used to compare the trial heats with those from the standard process in the same production period (**Figure 6**).

It was found that the average inclusion index of the trial heats was clearly lower than that of heats produced with the standard tundish. This observation holds for both investigated steel grades A and B. Moreover, we found that especially the higher inclusion indices of the standard process heats could mostly be avoided by employing the optimized tundish design. This is noteworthy since high inclusion indices are most often the result of a small number of larger inclusions, or even a single exceptionally large inclusion. Especially the occurrence of such big inclusions can cause severe problems for subsequent processing steps of the steel or even for the final applications. The plant trials therefore confirm that the “double-dam-weir” configuration improves the removal of non-metallic inclusions and further enhances the cleanliness of the investigated steel grades.

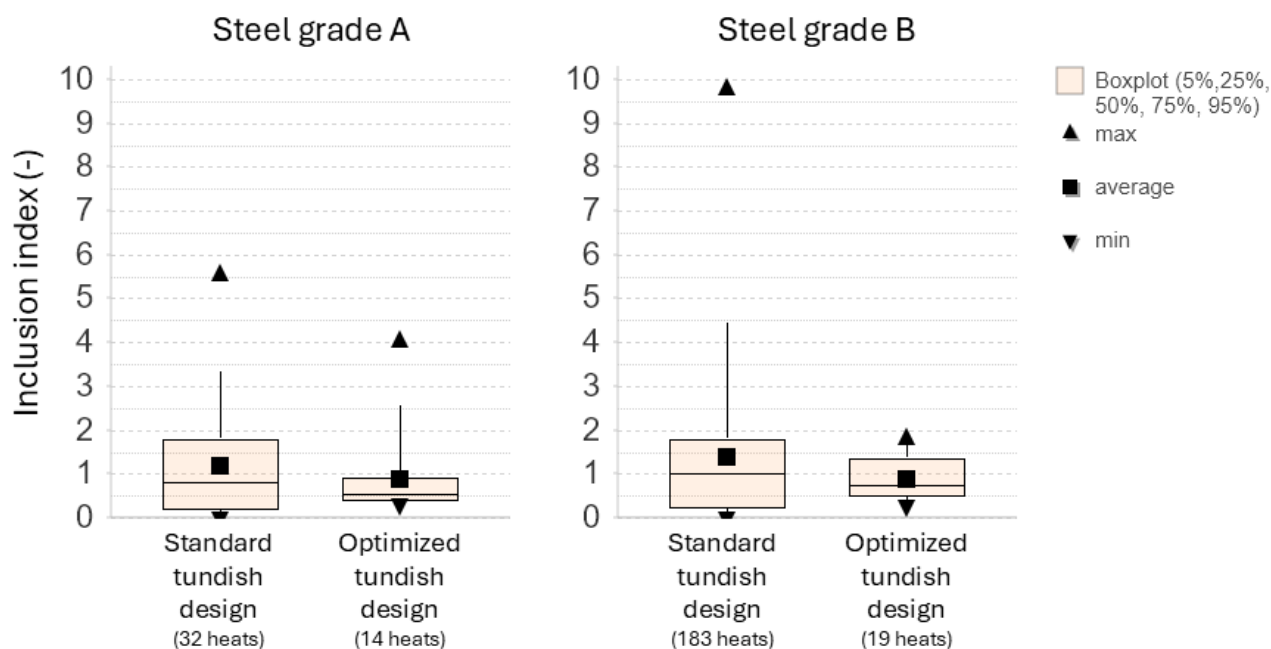


Figure 6 Boxplots comparing the inclusion indices of heats cast using the standard and optimized tundish designs for two high-quality, inclusion-sensitive steel grades

In addition to inclusion removal, the impact of a changed design on the tundish preparation before casting and its wear behavior during casting must be considered as well. Since the tundish furniture must be renewed for each casting sequence, the construction should be as easy and inexpensive as possible to be competitive. Additional tundish furniture as is necessary for the “double-dam-weir” configuration compared to the standard design will of course lead to additional construction time, cost and refractory wear and its consumption during casting. Finally, it should be assessed case by case whether the enhanced inclusion removal and thus better cleanliness of the steel product outweigh the increased cost of the “double-dam-weir” tundish configuration.

4. CONCLUSION

By means of CFD simulations the flow control elements of a 6-strand tundish of a billet caster were optimized. The “double-dam–weir” configuration with a pair of extra dams, each placed at 100 mm from the weirs on either side of the tundish center, was found to be the most suitable. This configuration minimizes the short-circuiting of steel from the in-gate region to the tundish trough and provides a uniform flow with reduced velocities between the weir and the outer dam and above the outer dam. These effects provide enhanced conditions for the removal of non-metallic inclusions thereby improving the degree of cleanliness as demonstrated by plant trials on inclusion sensitive Si-Mn-killed steel grades. Since a pair of extra dams must be employed for this tundish configuration, the additional cost has to be weighed against the cleanliness benefit for each use case.

REFERENCES

- [1] MAZUMDAR, D., GUTHRIE, R.I.L. The Physical and Mathematical Modeling of Continuous Casting Tundish Systems. *ISIJ International*. 1999, Vol. 39, pp. 524-547.
- [2] CHATTOPADHYAY, K., ISAC, M., GUTHRIE, R.I.L. Physical and Mathematical Modelling of Steelmaking Tundish Operations: A Review of the Last Decade (1999-2009). *ISIJ International*. 2010, Vol. 50, pp. 331-348.
- [3] ODENTHAL, H.-J., BÖLLING, R., PFEIFER, H. Numerical and Physical Simulation of Tundish Fluid Flow Phenomena. *Steel Research*. 2003, Vol. 74, pp. 44-55.
- [4] GUPTA, S., DEWAN, A. Performance Optimization of a Six-Strand Tundish. *World Journal of Mechanics*. 2013, Vol. 3, pp. 184-193.
- [5] ANSYS FLUENT 6.3.26. *User's Guide*. Lebanon, NH, USA: Fluent Inc., 2006.
- [6] DIN 50602. *Microscopic examination of special steels using standard diagrams to assess the content of non-metallic inclusions*. Berlin, Germany: Beuth Verlag GmbH, 1985.