Correlation between the Steel Quality and the Mould Fluid Flow Characteristics Induced by the GYRONOZZLE

G. Krumpel

The fluid flow characteristics in the mould have a significant impact on the quality of the cast product. The flow in a casting mould is influenced by the geometry of the casting nozzle and by electromagnetic stirring (M-EMS). To improve the quality of the as-cast product, the solidification structure shall be characterized by a large central equiaxed zone.

This paper summarizes the results describing the mould flow patterns induced by single port nozzles, multiport nozzles and by the GYRONOZZLE, a novel concept for improving the flow conditions in bloom and billet casting.

Based on the correlation of the modeling results with data obtained from industrial field trials regarding the solidification structure of the as-cast products it is concluded, that the Gyronozzle increases the efficiency of the electromagnetic mould stirring. A mould flow influenced by the port geometry of the GYRONOZZLE and optimized parameters for the electromagnetic stirring can improve the solidification structure of as-cast products.

1 Introduction

The steel producers are confronted with an increasing demand on steel quality. As the steel quality is influenced by the fluid flow in the mould, RHI MAGNESITA has a clear focus on the development of novel designs of submerged entry nozzles. Submerged entry nozzles are used for transporting the liquid steel from the tundish to the mould.

For billet and bloom casting, single port nozzles and multiport nozzles are used since many years. The fluid flow generated by a single port nozzle is characterized by a deep steel jet penetration and by a low meniscus turbulence. A multiport nozzle creates a steel flow perpendicular to the mould walls and a deep jet penetration is avoided. In the case of the single port submerged entry nozzle, the deep steel jet penetration is seen as a disadvantage as the non-metallic inclusions cannot be removed by floatation into the mould powder slag. The low turbulences in the upper part of the mould indicate a reduced heat flow towards the meniscus, which possibly has a negative impact on the mould powder slag melting.

Although the steel jet created by a multiport nozzle increases the probability for floatation of nonmetallic inclusions, the negative aspects, such as higher turbulences in the meniscus area and the high steel jet velocities and the impingement area, need to be considered.

The fluid dynamics are not only influenced by the nozzle design, but also by the electromagnetic stirring process in the mould (M-EMS). The electromagnetic stirring homogenizes the steel flow and positively influences the steel quality by increasing the area of equiaxed solidification.

The fluid flow created by the GYRONOZZLE was investigated by using computational fluid dynamics (CFD) and water modeling. The results are discussed in several publications [1, 2]. By using an electrically conducting liquid based on a low melting alloy, the Helmholtz-Zentrum Dresden-Rossendorf/DE has investigated in collaboration with RHI MAGNESITA the characteristics of the liquid flow modified by submerged entry nozzle geometry and the electromagnetic stirring [3]. The impact of steel flow modified by the GYRONOZZLE on the quality of alloyed low carbon and low alloyed medium-high carbon steel grades was investigated by Ona et al. [4] in frame of collaborative work of SIDENOR Basauri and RHI MAGNESITA.

This paper aims to discuss the correlation of various flow pattern simulation results with the observations obtained from casting trials.

2 Concept of the GYRONOZZLE

To support our customers to meet the increasing demand for casting high quality steel grades, RHI MAGNESITA has developed advanced nozzle geometries, such as the GYRONOZZLE. The GYRONOZZLE is characterized by a helical port geometry which induces a rotational flow in the mould (Fig. 1). As described by [1, 2] several benefits are associated with this concept:

Georg Krumpel
RHI MAGNESITA
1120 Wien
Austria

Corresponding author: *G. Krumpel*
E-mail: georg.krumpel@rhimagnesita.com

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Fig. 1 **Port geometry of the GYRONOZZLE**

- The rotational flow in the mould either reduces or supports the need for electromagnetic actuators.
- More efficient removal of the nonmetallic inclusions as a deep penetration of the steel jet into the mould is avoided.
- The steel mixing in the upper area of the mould is more efficient and this leads to a better mould powder melting rate. The improved mould powder melting rate supports the strand lubrification.
- In comparison to conventional multi-port design nozzles, the steel jet impingement on the solidifying steel shell is reduced.

Numerical and physical flow modeling attempts using CFD and water modeling were conducted to investigate the flow characteristics of the steel flow generated by the GYRONOZZLE, a single port nozzle and a conventional multiport nozzle for different mould types.

Water modeling with dye injection to compare the flow characteristics in a square mould generated by the GYRONOZZLE and single port nozzle are demonstrated in Fig. 2. The significant reduction of the steel jet penetration is obvious.

By using CFD modeling, the rotational flow structure induced by the GYRONOZZLE was evaluated for different mould sizes and geometries. In all cases a rotational flow pattern in the meniscus was observed. The flow patterns were stable and the velocity magnitude was < 0,3 m/s in all configurations. The flow characteristics are presented in Fig. 3, further details are described in [3].

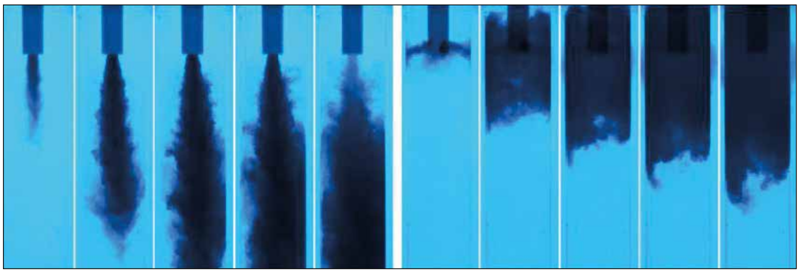

Fig. 2 **Comparison of the jet penetration by using a single-hole nozzle (l.) , and the GYRONOZZLE (r.) by using a water model with dye injection**

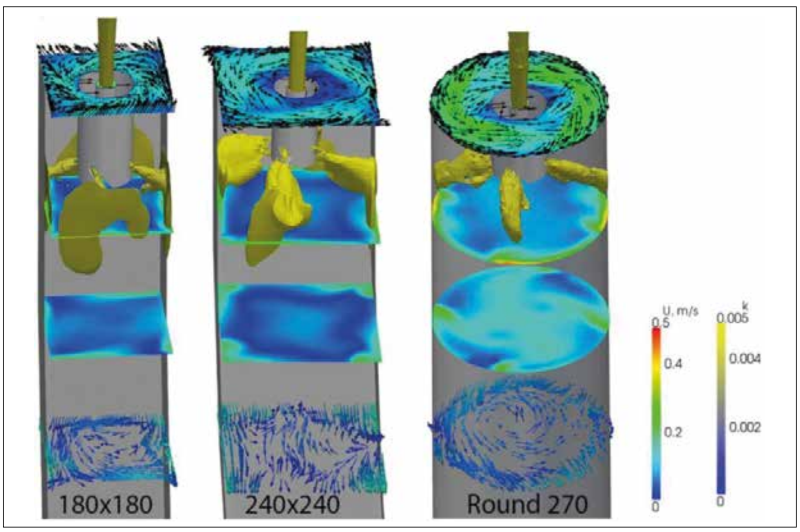

Fig. 3 **Velocity profile of the meniscus using the GYRONOZZLE for different mould sizes**

Several industrial trials with the GYRONOZZLE were successfully performed and have revealed advantages such as:

- a reduction of the oscillation marks;
- an increased steel cleanliness;
- a smoother and less turbulent mould level.

As all the above-mentioned simulations were conducted without considering electromagnetic stirring, the interaction of the GYRONOZZLE with a M-EMS was investigated by G. Hackl et al. [4]. In frame of their experiments and simulations, the interaction of the electromagnetic field with varying field strengths on the flow induced by a GYRONOZZLE and by a single port nozzle were compared. For the experiments, a GaInSn model fluid, which is liquid at room temperature, was used.

The experiments have shown, that the flow induced by a single port nozzle shows a significant rotational flow already at the weakest applied magnetic field strength (5,8 mT).

At stronger field strengths, a turbulent mould surface and the formation of vortices were observed. This clearly increases the risk for mould powder slag entrainment.

However, in comparison to the flow induced by the single port nozzle, the flow induced by the GYRONOZZLE shows a significant different behavior:

- The rotational flow in the upper area of the meniscus is already induced by the port geometry of the GYRONOZZLE. An increasing field strength has a comparatively lower impact on the flow characteristics. In general, the flow is more stable, the formation of vortices was not observed.
- The magnitude of the surface velocity is strongly influenced by the electromagnetic field strength.
- With an increasing distance from the meniscus, the rotational flow is established more strongly compared the flow characteristics induced by the single port nozzle. The influence of the electromagnetic field in the lower section of the mould is stronger.

Based on these experimental results, which are in good agreement with the results obtained by CFD modeling it is concluded, that the steel flow obtained by the usage of a GYRONOZZLE and a M-EMS should be beneficial in terms of the solidification structure in an as-cast product.

3 Results obtained from casting trials

It is state-of-the-art to use conventional multiport nozzles for casting steel grades with high quality demands.

The impact of the multiport nozzle design and the GYRONOZZLE on the quality of the as-cast products was investigated by SIDENOR Basauri in collaboration with RHI MAGNESITA in extended service trials [3]. The target of this collaborative work was to investigate if the flow patterns generated by the GYRONOZZLE and by mould stirring using a M-EMS can improve the solidification structure and the inner soundness of the as-cast products.

Prior to the casting trials, comparative CFD studies were completed. The results of the CFD studies have shown several benefits of the GYRONOZZLE in comparison to a multiport nozzle in terms of lower impingement velocity onto the mould wall, lower velocities in the mould meniscus area and a more homogenous and well-directed rotational pattern in the meniscus. A detailed description is of the modeling results can be found elsewhere [4].

The service trials have shown, that the GYRONOZZLE supports the formation of concentric rings in the mould powder cover. As the mould powder distribution was inhomogeneous in the first trial, the stirring energy of the M-EMS was reduced by 10 %. By reducing the stirring energy, a homogeneous mould powder cover was observed. It was observed, that the usage of the GYRONOZZLE in combination with optimized stirring parameters lead to an improved mould powder cover in comparison to the conditions achieved by using a multiport nozzle.

As described above, it is the target in steel casting to increase the central equiaxed zone and to reduce the columnar zone by electromagnetic stirring. The difficulty is, that the stirring is not that efficient, especially in case of flows induced by single port nozzles. This effect is even more pronounced in the upper meniscus area of the mould.

To obtain optimized swirling conditions over the entire length of the mould, the flow characteristics induced by the GYRONOZZLE and optimized electromagnetic stirring parameters were combined to achieve the best conditions for a fast and uniform removal of the superheat.

The positive effect of such a modified flow characteristic on the inner-quality of an as-cast product was clearly observed [3]. In comparison to the inner quality achieved by using a conventional multiport nozzle the central equiaxed zone has been increased by 15 % in average in case of low carbon content steel grades. The increased amount of the equiaxed grain structure has also improved the inner soundness of the as-cast units.

4 Summary and discussion

The modelling and simulation results are summarized as follows:

CFD modeling, physical modeling techniques such as water modeling and simulating the effects of the electromagnetic stirring on the flow pattern of an electrically conducting model liquid induced by various nozzle designs have shown, that the flow patterns generated by a single hole nozzle, a multiport nozzle and the GYRONOZZLE are different:

Whereas the usage of a single port nozzle results in a deep steel penetration, the flow patterns created by a multiport nozzle and the GYRONOZZLE are characterized by a shallow rotation in the meniscus area. A deep penetration of the steel jet int the mould is avoided.

In case of a single port nozzle a rotational flow is induced by electromagnetic stirring and the rotational flow is mainly observed in the upper part of the mould.

The rotational flow is entirely controlled by the M-EMS and is characterized by an unstable mould surface and by the formation of vortices at higher field strengths.

The port geometry of the GYRONOZZLE strongly influences the rotational flow in the mould (mainly in the meniscus area), but is also detected in deeper areas of the mould.

It is therefore stated, that the GYRONOZZLE improves the efficiency of the electromagnetic stirring.

The main difference between the flow patterns induced by a multiport nozzle and the GYRONOZZLE is the lower velocity impingement of the mould wall and the characteristics of the rotational flow. In case of the GYRONOZZLE, the achieved velocity profile in the meniscus surface shows a well-directed flow component. It is therefore assumed, that the rotational flow induced by the GYRONOZZLE is more stable compared to the flow induced by a multiport nozzle.

Circular rings observed in the mould powder casting powder during casting with multiport nozzle or the GYRONOZZLE indicate the existence of a rotational steel flow in the mould.

The observation, that the usage of the GYRONOZZLE at a given electromagnetic stirring force results in a more homogeneous mould powder cover, correlates with the CFD results, which predict a well-directed rotational flow in the mould.

A more pronounced rotational flow even in deeper areas of the mould lead to a better solidification pattern: the area of the equiaxed solidification is increased.

5 Conclusions

The modification of the steel flow by the port geometry of the GYRONOZZLE and by an optimized electromagnetic mould stirring, results in the formation of a comparatively bigger area of equiaxed crystals in the as-cast steel sample. It is concluded, that the unique port geometry of the GYRONOZZLE increases the efficiency of the electromagnetic mould stirring in a continuous casting process.

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