

Single-Port Submerged Entry Nozzle for Billets to Reduce Alumina Clogging (SSB-Nozzle)

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Abstract

Alumina clogging is one of the issues associated with single-port submerged entry nozzles for blooms and billets. To address this, we developed a product that combines the SSB-Nozzle (Shinagawa Self-Braking)—a design expected to reduce alumina clogging and discharge flow velocity— and existing technologies such as “carbon-free inner material” and “annular step inner geometry”. Operational evaluations gave excellent results in which a significant reduction in alumina clogging was confirmed.

1. Introduction

Continuous casting machines for blooms and billets employ various types of submerged entry nozzles (hereafter referred to as SEN). For billet casters, a single-port SEN with one outlet port at the bottom is often used. Typically, single-port SENs are either cylindrical or tapered to be smaller towards the outlet port.

Because single-port SENs for the billet have a small inner bore diameter, even minor alumina clogging inside the bore can cause a significant decrease in flow rate, leading to a shortened casting sequence. Thus, alumina clogging is one of the operation time determining factors of such SENs. On the operational side, adding Ca to molten steel for inclusion modification is a common measure to reduce clogging; however, alumina clogging still occurs in aluminum-killed steels. Meanwhile, several studies indicate that carbon-free materials or $\text{CaO}\cdot\text{ZrO}_2\text{-C}$ (CZ-C) materials can improve the performance of the SEN inner liner¹⁻³⁾; however, clogging remains an issue.

In addition, single-port SENs used for billets tend to produce strong downward flow, which can carry

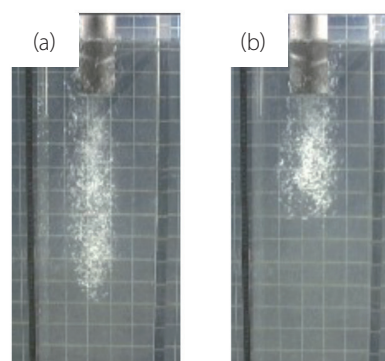


Fig. 1 Characteristics of SSB-Nozzle.
(a): conventional, (b): SSB-Nozzle)

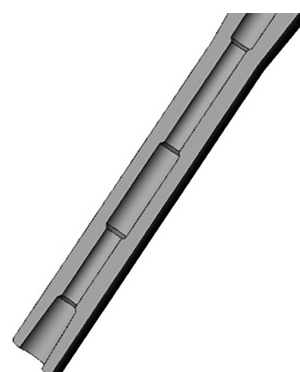


Fig. 2 Design of SSB-Nozzle.

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inclusions and bubbles deep into the mold. When clogging occurs, the inner diameter is further reduced, which intensifies the downward flow and increases penetration depth, potentially degrading steel quality. Therefore, alumina clogging in single-port SENs for the billet significantly impacts stable operation and steel quality.

We previously reported that a reverse-taper outlet port geometry can mitigate deep penetration in single-port SENs⁴⁾. We refer to this nozzle as the SSB-Nozzle (Shinagawa Self-Braking). It is capable of braking discharge flow even when flow velocity is increased by the constricting inner bore geometry (i.e. annular step), proving effective in reducing penetration depth (Fig. 1, 2). Since increased flow velocity is expected to help reduce clogging, we developed a single-port SEN for the billet that combines the SSB-Nozzle with an annular step inner geometry using a carbon-free liner with improved wettability to molten steel. This paper describes its features and clogging suppression performance in actual operation.

2. Features of the Anti-Clogging Single-Port SEN for Billets

2. 1 Structural features

Fig. 3 shows a schematic of the lower portion of the anti-clogging single-port SEN for billets. Two annular steps (5 mm constricted sections) were created in

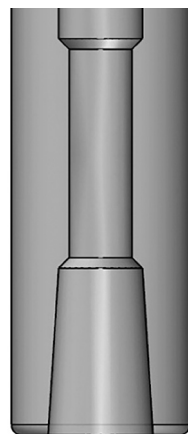


Fig. 3 Shape around the outlet port of SSB-Nozzle.

the bore. They serve to correct biased flow caused by flow-control refractories (stopper rod or slide gate plate) and increase flow velocity through reduced bore diameter. The lower end adopts a reverse-taper structure that widens the inner diameter to reduce port velocity.

Fig. 4 compares Computational Fluid Dynamics (hereafter referred to as CFD) simulation results for a conventional straight inner bore and the developed anti-clogging SEN (Fig. 3). The CFD conditions assumed a 200 × 200 mm mold and a casting speed of 1.0 m·min⁻¹, using the commercial PHOENICS program with the *k-ε* turbulence model. The results showed increased flow velocity around the annular step and reduced port velocity due to the reverse taper. Consequently, penetration depth is shallower compared to the conventional design. This indicates that the developed nozzle can suppress clogging by accelerating flow through the bore and improve steel quality by reducing deep penetration.

2. 2 Application of anti-clogging material

Various approaches have been studied to prevent alumina clogging. Carbon-free materials have been widely used as they suppress CO and SiO gas generation inside refractories during casting thereby maintaining a smooth working surface by limiting graphite dissolution into molten steel⁹⁾. CZ-C materials, which react with inclusions to create a semi-molten

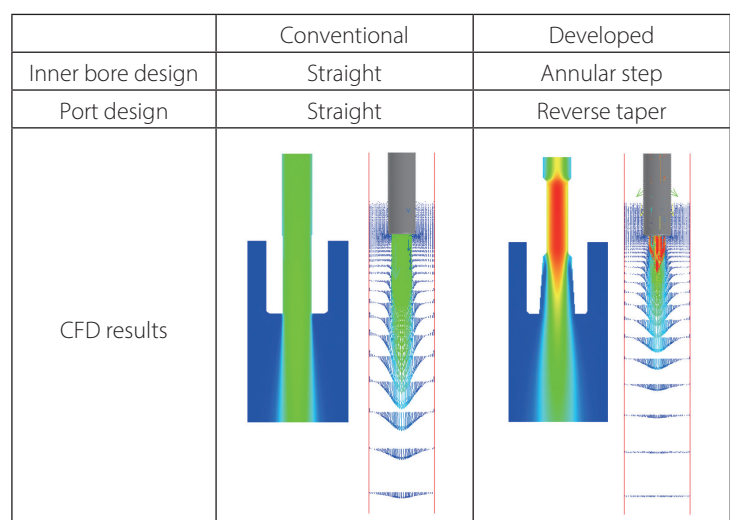


Fig. 4 CFD results of single port SEN for billet caster.

Table 1 Typical physical and chemical data of spinel flux inner material

Material		Spinel-Flux
Physical property	Apparent porosity / %	15.5
	Bulk density / g·cm ⁻³	2.80
Chemical composition / mass%	MgO	23
	Al ₂ O ₃	59
	SiO ₂	8
	CaO	7

surface, are also employed⁶⁾; however, CZ-C materials exhibit significant expansion and are sensitive to preheating conditions, making carbon-free materials more common for inner liners.

In this paper, we adopted a spinel flux material among our carbon-free materials, considering its superior ability in maintaining a smooth working surface. Spinel was chosen because billet steels are typically Ca-treated, and basic materials offer better corrosion resistance to such steels. Table 1 shows the typical properties of the spinel flux used.

3. Results of Actual Application

Fig. 5 illustrates the cross-sections of both the conventional and developed SENs after a casting sequence from the same tundish. The conventional SEN is made of alumina-silica-graphite material throughout its inner liner. The developed nozzle was lined with the mentioned spinel-flux material for a certain length above the reverse-taper section, which in turn is of ZG material. While the conventional nozzle had much alumina clogging near the outlet port, it was clearly suppressed in the developed nozzle. The developed nozzles consistently performed well and have been adopted by the same caster since then.

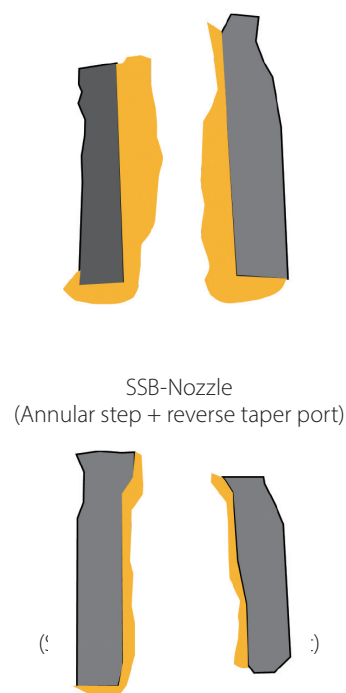


Fig. 5 Results of commercial application.

4. Conclusion

We developed a single-port SEN for the billet designed to suppress alumina clogging and presented its features and operational results. The nozzle structure combines annular steps, which accelerate flow to reduce clogging, and a reverse-taper outlet port, which mitigates deep penetration of inclusions. Additionally, the inner bore employs a carbon-free material with a smooth working surface to prevent alumina adhesion. Actual application confirmed a significant reduction of alumina clogging in the inner bore. This developed nozzle is expected to effectively reduce clogging, contributing to improved operational time and steel quality.

References

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