SENs for Quality Improvement of Steel in Bloom or Billet Caster

Hiroyasu NIITSUMA*1 Yukio OHKAWA*2
Shinsuke INOUE*3 Takayuki MATSUNAGA*4

Abstract

The structure of SEN controls the molten steel flow pattern in the mold and influence on steel quality.

Using a water model test and CFD calculation, we developed a SEN structure that can optimize the molten steel flow pattern in the mold for bloom or billet continuous casters.

It became clear that a stable swirling flow in the mold was created using "Bend port" SEN which had unique ports on the side of the nozzle. In addition, improvement of steel quality was confirmed by the results of an actual test in a round billet caster.

A Mogul SEN with a reverse-taper port which had mogul projections in the bore and an increased nozzle diameter, solved the biased outlet flow problem and decreased the depth of the outlet flow.

1. Introduction

Various kinds of Submerged Entry Nozzles (SEN) structures are used at bloom and billet casters. The molten steel flow pattern in the mold varies according to SEN structure, and it has various influences on steel quality. For example, a downward single outlet port SEN is widely used for billets. In this case, the molten steel is strongly discharged downward from the port causing inclusions and gas bubbles to easily penetrate deep into the mold. As a result, inclusions and gas bubbles can be caught in the solidified shell and cause defects in the steel. In addition, insufficient heat supply to the meniscus may induce solidified deckle and retard melting of the mold flux.

On the other hand, SENs that have multiple ports are widely applied in bloom casters. In this case, the outlet flow discharged from the SEN impinges against the mold wall and separates into two flows. This flow pattern prevents deep penetration of the inclusions and gas bubbles and improves heat supply to the meniscus. However, because of the close distance between nozzle and mold wall, the solidified shell thickness may become uneven due to the effect of strong impingement of the outlet flow against the mold wall. The uneven solidified shell growth may cause cracking or surface defects on the steel.

Therefore, in addition to the application of an electromagnetic stirring (EMS) system, improving the SEN design has been widely considered in order to optimize the flow pattern in the mold.[1)-5)] We have developed unique structures that are effective in controlling the flow pattern in the mold for both single port SENs and multiple lateral port SENs in water model simulation tests. In this report, we report on the laboratory test results and actual results.

2. Swirling Flow SEN

2. 1 Water model test 1

In order to improve the steel quality by controlling the flow pattern in the mold, some unique SEN designs have already been proposed[2)-4)] which could generate a swirling flow in the mold. Because these proposed designs improved the steel quality, generating a swirling flow in the mold can be considered to be an effective method. Therefore, we also investigated a novel swirling flow SEN design. We carried out a yes or no evaluation of the swirling flow outbreak in the mold in examination 1. Fig. 1 shows schematic drawings of the ports that were examined. Although a curved port is the most advantageous design to generate a swirling flow in the mold, it is difficult to manufacture. Alternatively, we designed bend ports that are favorable for production. In addition, both, decentralized ports and one-side taper ports were examined because the designs were described in some articles. Table 1 shows the test conditions. The flow pattern in the mold was investigated by the motion of plastic beads that have a lighter specific gravity than water.

As a results of test 1, in the case of the decentralized port

*1 Managing Research Engineer, Research Dept. No. 3, Research Center
*2 Research Dept. No. 3, Research Center
*3 Manager, Technical Section, East Japan Works
*4 General Manager of Technical Dept., Shinagawa Rongyuan Refractories Co., Ltd.

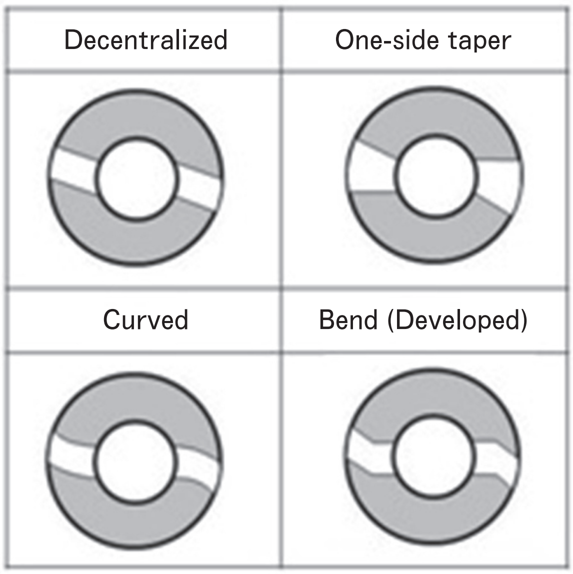


Fig. 1 Port designs tested in water model test 1.

Table 1 Test conditions of water model test 1 and 2

	Test 1	Test 2
Mold size	ϕ190 (Round billet)	ϕ190 (Round billet)
Casting velocity	1.2 m/min	1.2 m/min, 1.7 m/min
Immersion depth	155 mm	155 mm
Flow control	Stopper	Stopper
Bottom bore	0	0, ϕ18, ϕ25

nozzle and the one-side taper nozzle, a swirling movement did not occur in the mold although the particles moved in an up and down direction. On the other hand, both the curved port nozzle and the bend port nozzle generated a stable swirling movement in the mold (Fig. 2). In other words, we confirmed that the bend port nozzle could easily generate a swirling flow in the mold easily.

2. 2 Evaluation of "Bend port" SEN

We performed water model test 2 using a "Bend port" SEN. In this SEN, two of "Bend port" and a bottom port were opened. Three different bottom bore diameters were prepared (0, ϕ18 and ϕ25). Table 1 and Fig. 3 show the test conditions. We also carried out CFD calculations

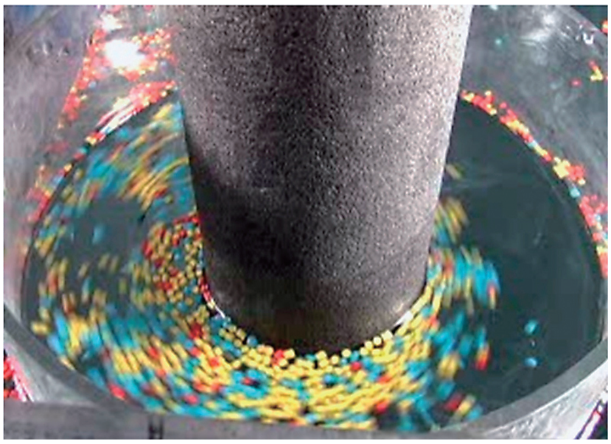


Fig. 2 Swirling flow generated by "Bend port" SEN.

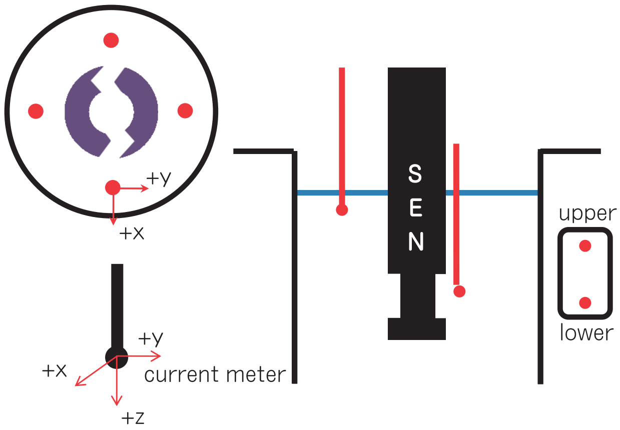


Fig. 3 Flow velocity measurement locations and axial direction of current meter.

in order to evaluate the flow pattern in the mold. PHOENICS was used as the CFD program for this study. In addition, the k-ε model was used as a turbulence model. As the bottom port diameter became larger, the outlet speed from the "Bend port" decreased. Table 2 shows the measured results for the outlet flow velocities. When comparing the top and bottom measuring points, the flow velocity at the bottom can be recognized to be faster than the top. It became clear that the flow direction from the top of the outlet port was strong in the Y-direction, which is in a tangential direction to the SEN. Fig. 4

Table 2 Outlet flow velocities (Bottom bore : ϕ18)

Flow velocity : cm/sec		Velocities to each axial direction			Composed velocities
		X	Y	Z	
Vc at 1.2 m/ min	Upper	14.3	-20.9	-2.5	26.2
	Lower	57.9	-8.9	8.1	59.7
Vc at 1.7 m/ min	Upper	23.2	-28.0	-9.0	39.3
	Lower	62.5	-5.7	7.8	65.7

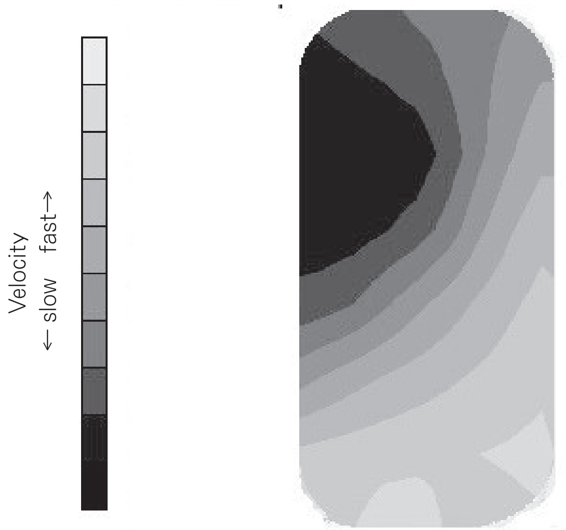


Fig. 4 Flow velocity distribution at outlet port (CFD calculation).

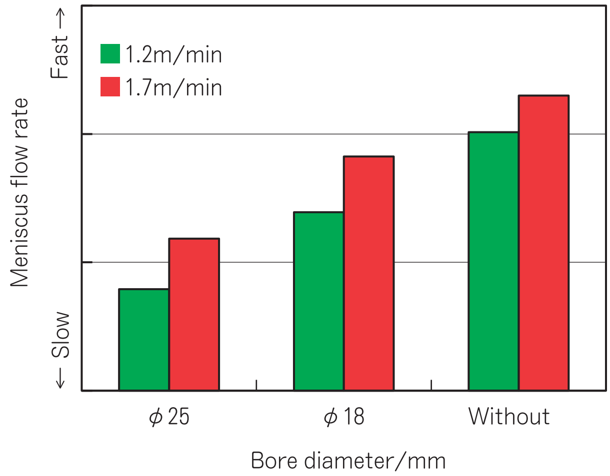


Fig. 5 Flow velocity at meniscus.

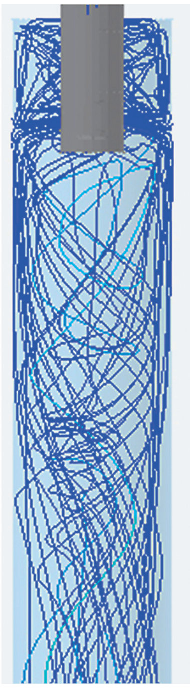


Fig. 6 CFD-calculated streamline for "Bend port" SEN.

Fig. 7 Appearance of "Bend port" SEN after use.

shows the velocity distribution at the outlet port by CFD calculation. The outlet flow velocity at the bottom area is faster than the top area, which is the same result as water model test 2. The flow velocity distribution in a horizontal direction of the outlet port, suggests that the velocity on the right-side, on the outside of the bend, is faster than the left-side.

In the meniscus, a stable swirling flow occurred which was similar to water model test 1. As shown in Fig. 5, as the casting velocity increased, the meniscus velocity also increased. In addition, it was clear that the meniscus velocity could be adjusted by changing the diameter of the bottom bore. Fig. 6 shows a streamline of the entire mold by CFD. The swirling flow pattern extends to a position that was deeper than the SEN tip. All of the fluid in the mold was rotated.

2. 3 Actual results

Fig. 7 shows the appearance of a used "Bend port" SEN. Because the structure of the outlet port did not change, it is thought that the bend structure functioned effectively during use. The appearance of the billet that was cast using this SEN without EMS is shown in Fig. 8.

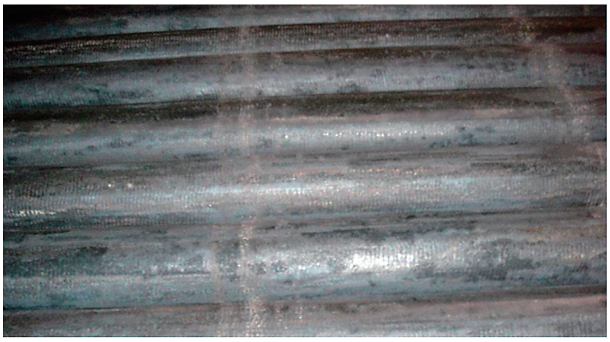


Fig. 8 Appearance of the billet cast by "Bend port" SEN.

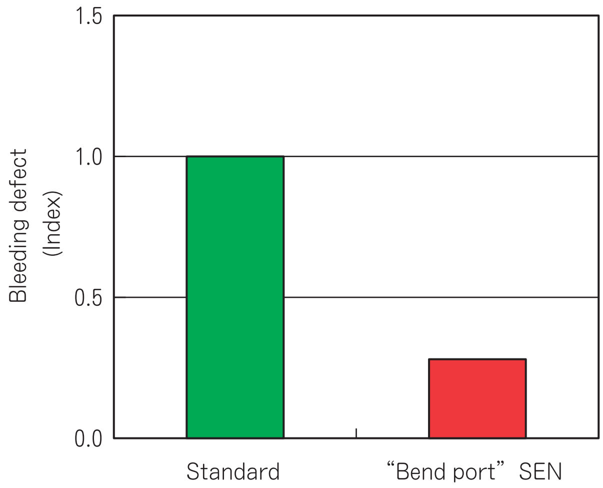


Fig. 9 Comparison of the bleeding defect ratio.

Table 3 Test conditions

Mold size	240 x 240 mm
Casting velocity	0.9 m/min
Immersion depth	100 mm form the tip of SEN
Flow control	Sliding plate (3 layer)
Air injection	2 L/min

The surface of the billet was smoother than in the cases where common SENs were used. As shown in Fig. 9, the ratio of bleeding defects was improved. A swirling flow occurred in the mold when using the bend port SENs, and the surface quality of the billet was confirmed to be improved.

3. Mogul SEN with Reverse-taper Port

A reverse-taper port single port SEN is known to be an effective structure for suppressing the penetration depth of the outlet flow. However, in the case of a reverse-taper port, the influence of biased flow is clear. Therefore, we introduced mogul projection structures to prevent biased flow in the reverse-taper port SEN.[5), 6)] Fig. 10 shows some schematic drawings of the SEN design.

We measured the downward outlet flow penetration depth of the single port SEN. Table 3 shows the test conditions. We injected a small amount of air (2 L/min) from a nozzle installed in the upper part of the SEN and observed the arrival depth of air bubbles in the mold. As shown in Fig. 11, in the case of a "standard" straight nozzle, gas bubbles penetrated to a deeper position in the mold (500mm from the meniscus). In addition, the direction of the outlet flow was not perpendicular but biased because of slide gate throttling. Many inclusions and gas bubbles are thought to have been carried by the biased flow. In the case of the reverse-taper port structure, the penetration depth of the bubbles was suppressed.

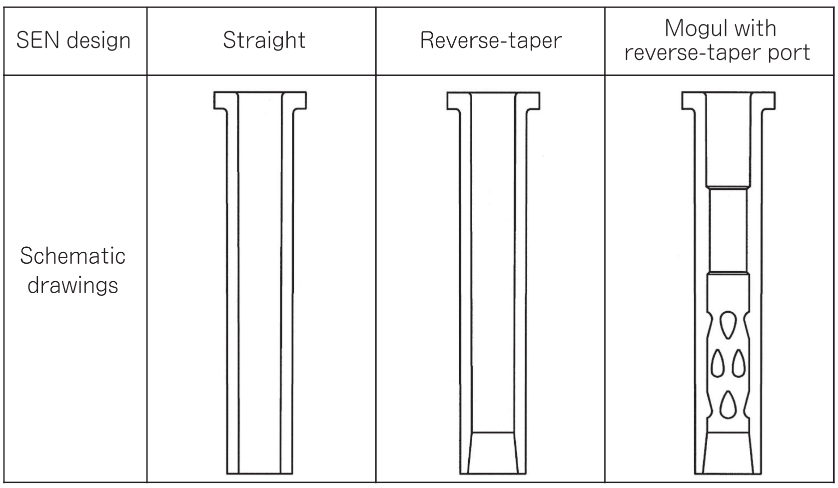


Fig. 10 Various shapes of single port SEN.

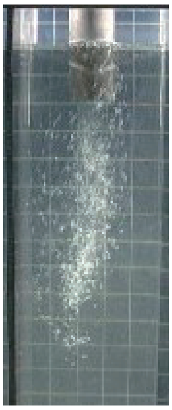
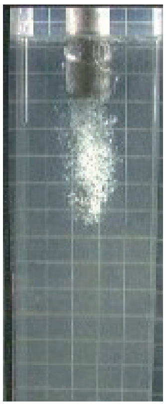
SEN design	Straight	Mogul with reverse-taper port
Water model simulation		
Penetration depth	Depth = 500mm	Depth = 250mm

Fig. 11 Water model test results of single bore SEN.

Fig. 12 Cut section of "Mogul with reverse-taper port" SEN.

However, a biased flow still occurred. Because of the influence of the biased flow, the penetration depth of the bubbles was increased locally and was not improved enough. With the mogul nozzle, the molten steel flow collides with the projections on the inside of the tube, and the biased flow is changed into a homogenous flow by the moguls. As shown in Fig. 11, The mogul SEN with a reverse-taper port realized a shallow and even outlet flow. Fig. 12 shows the cut section of a mogul SEN with a reverse-taper port after use. Because the reverse-taper structure and mogul structure remained well in act after use, we expect it to improve steel quality.

4. Conclusions

We developed unique SEN structures that can control the molten steel flow pattern in the mold to improve steel quality for bloom or billet casters. The "Bend port" SEN can generate a stable swirling flow in the mold. The "Mogul SEN with reverse-taper port" can suppress the penetration depth of outlet flow and biased flow.

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