Flow Optimization in the Mould by Port Design Improvement of Submerged Entry Nozzle

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Abstract

In accordance with the recent requirement for the optimum flow in the mould of continuous casting process in steel mills all over the world, improvements of steel flow with the port design of submerged entry nozzle (SEN) have been achieved to some extent. Nowadays, it has been getting more and more important to produce high-quality steel and realize high productivity in continuous casting operation. In this report, improved port design for SEN which is able to achieve high quality steel with high productivity by optimizing the steel flow in the mould and minimizing mould powder inclusion by reducing the mould fluctuation with optimum flow from the port of the SEN is reported.

1. Introduction

The improved port design is based on the general two ports design of submerged entry nozzle (SEN) for normal slab continuous caster. The improved port design have been developed by computational fluid dynamics (CFD) and water modeling (1/1 scale) compared with conventional design as first step to optimize the flow in the mould, after that the improved SEN have been used in actual casting compared with conventional SEN. The related parameters in continuous casting and steel quality have been investigated and evaluated.

2. Improvement of SEN Port Design

The consideration of the flow from the port in general SEN port design (rectangular or oval shape) for normal slab continuous caster, when the port cross section is divided to three portions (upper, middle and lower), the main flow is observed at lower portion of port with large flux. This large flux hit to mould narrow face and brings on the mould fluctuation and mould powder inclusion caused by large reversed flow. Therefore it is important to get the equalized flow from both ports and homogeneous flow in whole portion of the port in order to optimize the flow in the mould. In this development of the flow optimization in the mould, it is applied the small steps to both inner port wall as the improved port design shown in **Fig. 1**. With the improved port design the flow from the port is observed not only at lower portion of the port but also at upper and middle portions of the port. As the result it is verified the reduction of the mould fluctuation by decreased reversed flow. The comparison of the port design between current and improved is shown in **Fig. 1**.

3. Evaluations of the Flow in the Mould

3.1 Analysis by the Computational Fluid Dynamics (CFD)

The CFD analysis is introduced and done to find the applicable port design which can optimize the flow in the mould as first step. The example of comparison of flow velocity distributions in the mould by CFD is shown in **Fig. 2** with condition (through put corresponding the molten steel 3.0 ton/min, mould size 234mm thickness×1,500mm width). It is verified that the improved design shows optimized flow in the mould and also slower flow velocity at meniscus compared to current design.

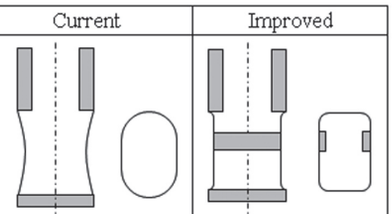
		Current	Improved
Port design			
Inner diameter / mm		80	80
Port dimension / mm	Width	80	80
	Height	130	100
Port angle		Horizontal	

Fig. 1 Comparison of SEN design.

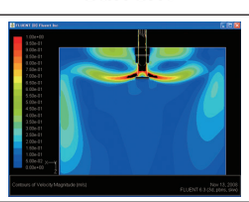
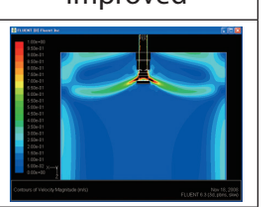
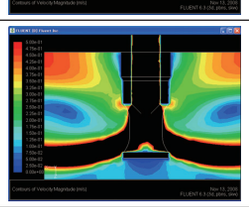
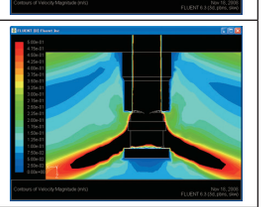
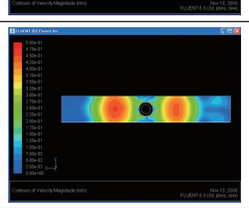
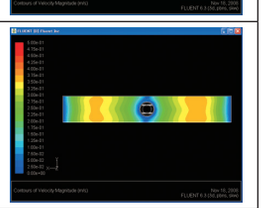
	Current	Improved
Front view		
Near ports		
Top view		

Fig. 2 Comparison of the flow by CFD.

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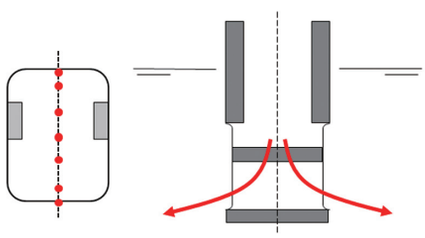
3.2 Evaluations by Water Modeling

As the flow evaluation for improved port design, the water modeling (scale 1/1) is used. The port velocities (measurement of the average velocities on each portion within 1 min by pitoh tube velocity meter) and meniscus velocities (measurement at both (left and right) center position between mould and SEN in 3 min by propeller velocimeter) are measured and evaluated. The details of the velocities measurement positions are shown in **Fig. 3** and **Fig. 4**.

4. Evaluation Results by Water Modeling

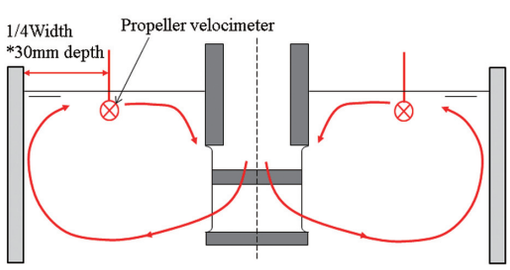
4.1 Flow Velocity Distributions at both Ports

As the example of comparison of flow velocity at both ports, the measurement result with the water modeling condition (through put corresponding the molten steel 3.7ton/min, mould size 234mm thickness × 1,500mm width) is shown in **Fig. 5**. It is verified that the improved design has the flow velocities at upper and middle portions of port compared to current design.



Measurements of flow velocity at each red dot positions of center of both ports.

Fig. 3 Measurement of flow velocities at both ports.



Measurement of flow velocity at positions of 1/4 mould width for both sides at the same time.

Fig. 4 Measurement of flow velocities at meniscus.

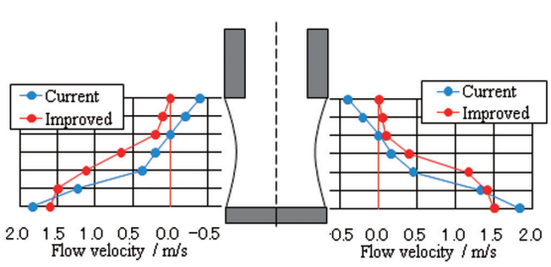


Fig.5 Comparison of flow velocity distributions at both ports.

4.2 Flow Velocity at Meniscus

As the example of comparison of flow velocity at meniscus, the measurement result in 3 min with the water modeling condition (through put corresponding the molten steel 3.7ton/min, mould size 234mm thickness × 1,500mm width) is shown in **Fig. 6**. It is verified that the improved design shows less velocity variations and stable flow velocity in 3 min compared to current design. And the comparison of average meniscus velocity between left and right and variation of flow velocity are shown in **Fig. 7**. It is verified that the improved design shows slower average flow velocity at meniscus and stable flow velocity compared to current design.

4.3 Through Put and Flow Velocity

The relationships between through put and flow velocity at meniscus in several different conditions (mould width and through put) and flow velocity variations are shown in **Fig. 8** and **Fig. 9**. It is verified that the current design shows the increasing of the flow velocity and velocity variation at meniscus with an increase the through put. On the other hand, it is verified that the improved design shows the reduction for increasing of the flow velocity and velocity variation at meniscus with an increase the through put compared to current design.

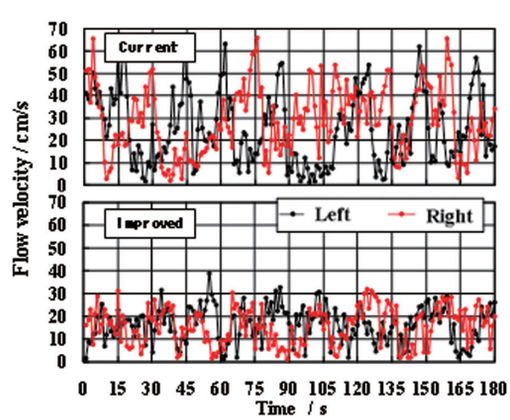


Fig. 6 Comparison of flow velocity variations at meniscus in 3 min.

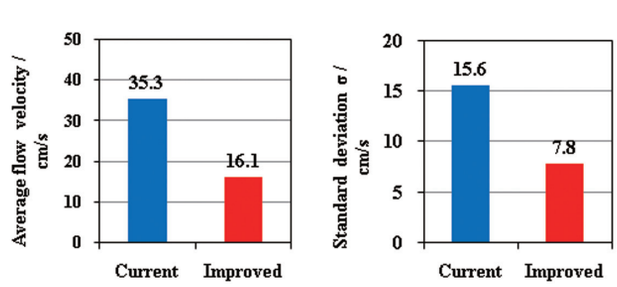


Fig. 7 Comparison of average (a) and standard deviation (b) for flow velocity at

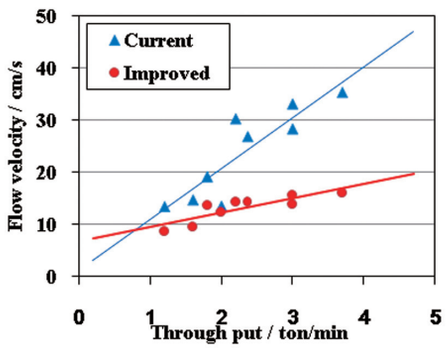


Fig. 8 Relationship between through put and flow velocity at meniscus.

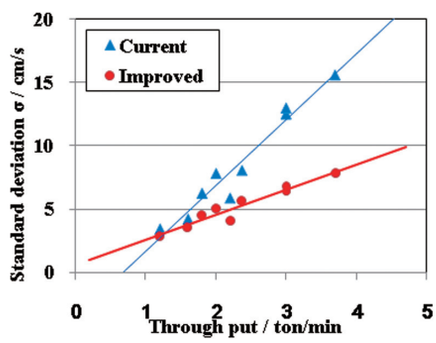


Fig. 9 Relationship between through put and standard deviation for flow velocity at meniscus.

5. Evaluation in Actual Casting

5.1 Comparison of SEN Alumina Adhesion

In the actual casting with SEN improved port design with conventional alumina graphite material at immersed body part showed bigger amount of alumina adhesion especially around port area compared to current design SEN. The example of the comparison of flow velocity distributions in the SEN port simulated by CFD between current design SEN and improved design SEN is shown in **Fig. 10**.

It is verified that the flow velocity around the steps and below the steps in the improved design SEN is slow due to the sudden change of the flow direction by the steps. It is estimated that the alumina adhesion created around the steps and below the steps faster than current design SEN.

Therefore the anti-adhesion material which contains calcium oxide in order to prevent alumina deposition by getting the reaction between calcium oxide in the refractory and alumina in the molten steel at immersed body part was introduced in order to reduce the alumina adhesion around port area which causes the un-even flow from the ports and the unscheduled SEN changes or unscheduled casting termination. The comparison of alumina adhesion at port and inner bore during the casting between current design SEN with conventional alumina graphite material and improved design SEN with anti-adhesion material are shown in **Fig. 11** and **Fig. 12**. The SEN alumina adhesion is evaluated with open ratio which is calculated with the dimensions after use divided by initial dimensions at port and inner bore.

It is verified that the open ratio at port and inner bore for improved design SEN with anti-adhesion material showed similar tendency to current design SEN with conventional alumina graphite material.

Later in the text, the improved port design SEN is applied anti-adhesion material at immersed body part and the current design SEN is applied conventional alumina graphite material.

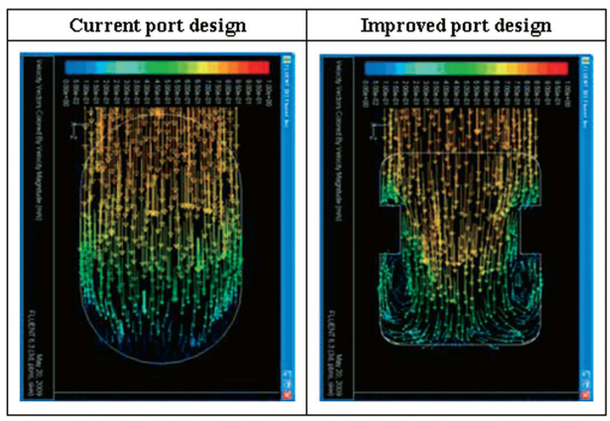


Fig. 10 Comparison of flow velocity distributions in the SEN port.

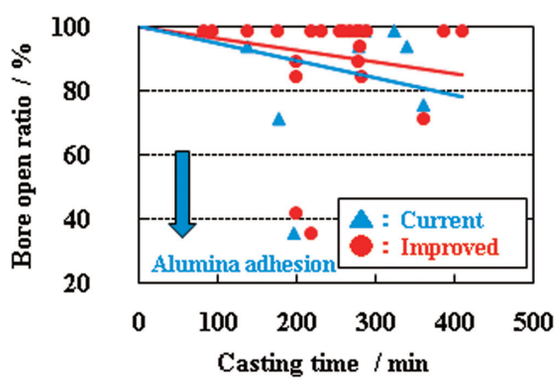


Fig. 11 Comparison of SEN port open ratio.

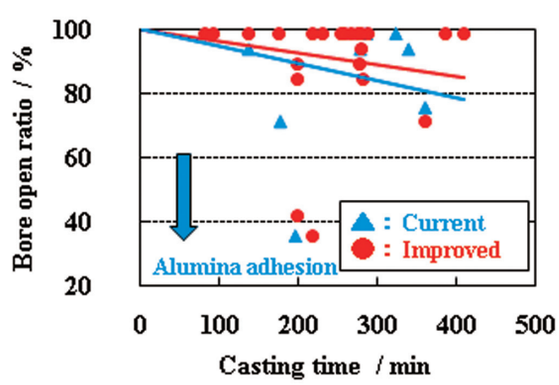


Fig. 12 Comparison of SEN inner bore open ratio.

5.2 Comparison of SEN Service Life

The actual casting for SEN improved port design is carried in slab continuous caster in order to evaluate and investigate the related parameters in continuous casting and steel quality compared to current design SEN. The comparison of SEN service life between current and improved is shown in **Table 1**. It is verified that the improved SEN shows almost same service life time as current SEN.

5.3 Evaluation of the Flow in the Mould

As the evaluation of the flow in the mould, the thermal distribution in the mould which is provided by thermocouple where is located around the mould is applied. As the evaluation of the mould fluctuation, the amount of mould fluctuation during the casting is applied.

5.4 Evaluation Result of Thermal Distribution in the Mould

The example of comparison of thermal distribution in the mould between current design SEN and improved design SEN is shown in **Fig. 13**. These SENs were used in same time for 80 min. It is verified that the improved design SEN showed less variation of thermal distribution between mould loose and fixed faces compared to current design SEN.

5.5 Evaluation Result of Mould Fluctuation

The example of comparison of the amount of mould fluctuation during the casting between current design SEN and improved design SEN is shown in **Fig. 14**. These SENs were used in same time for 275 min. It is verified that the improved design SEN showed small amount of mould fluctuation in whole casting speeds compared to current design SEN.

Furthermore as the evaluation of mould fluctuation for specific steel grades C,D,E and F, the comparison of average mould level change during the casting is shown in **Table 2** and **Table 3**. It is verified that the improved design SEN shows better mould level change (at least same) on different casting strand compared to current design SEN.

Table 1 Comparison of SEN service life

	Maximum service life / min	Average service life / min	Number of SEN / pcs
Current	359	239	26
Improved	408	245	41

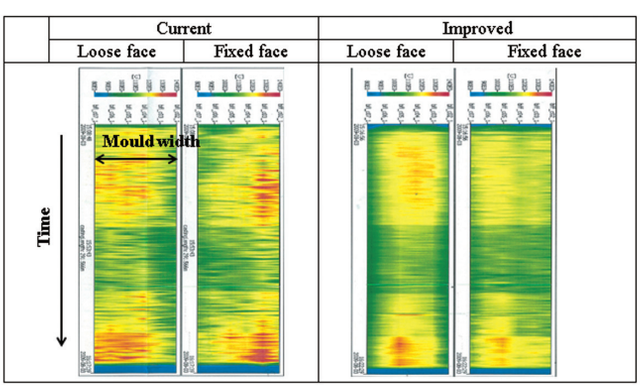


Fig. 13 Comparison of thermal distributions in the mould.

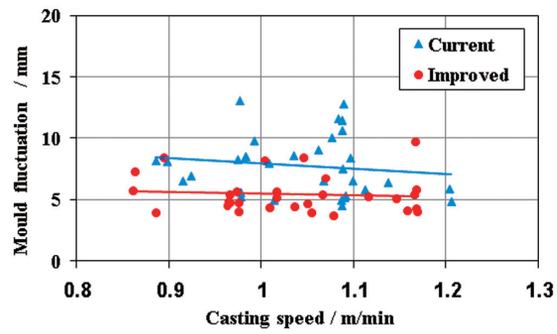


Fig. 14 Comparison of the amount of mould fluctuation.

Table 2 Comparison of average mould level change (Improved design on strand A).

Strand	A	B
Grade	Improved	Current
C / mm	7.2	9.6
D / mm	10.1	11.3

Table 3 Comparison of average mould level change (Improved design on strand B).

Strand	A	B
Grade	Current	Improved
E / mm	6.3	4.1
C / mm	6.4	6.6
F / mm	6.9	6.9

6. Conclusions

As the conclusion for the development of SEN port design for optimizing the flow in the mould, it is considered that the following points have been achieved.

The flow optimization in the mould is achieved with improved port design by getting the equalized flow from both ports and homogeneous flow in whole portion of the port.

The flow stabilization of mould fluctuation is achieved with improved port design in case of increasing the through put (increasing the casting speed).

This will also contribute to reduce the mould powder inclusion.

In the results, it is verified that the steel yield for specific steel grades improve 18.5 and 16.7% (on each strand) with improved design compared to current design directly.