DEVELOPMENT AND APPLICATION OF VENTURI NOZZLE WITH ANTI-CLOGGING MATERIAL[1]

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Abstract

In the continuous casting process, the flow pattern of molten steel in the mold is critical to produce high quality steel. It is therefore important to develop methods to prevent alumina clogging. The use of special anti-clogging materials in the bore and ports of the SEN is now commonly used to reduce deposition. A recent development is the advanced venturi nozzle that can produce uniform flow of steel in the SEN bore and ports and prevent alumina deposition generated by biased flow. Combining the venturi nozzle design with anti-clogging materials has given good results in clogging reduction, with resulting improved steel quality.

Key words: Anti-clogging; SEN; Continuous casting; High quality steel.

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1 INTRODUCTION

In the continuous casting process, alumina clogging in the inner bore of the SEN restricts the life of the refractory components. Carbon-free alumino-silicate anti-clogging materials, pressed as the inner layer of the SEN, are currently used to solve clogging problems.[1,2] However, under some operating conditions, alumina deposition still develops. By preheating to high temperature, the texture of the carbon-free material densifies, its surface becomes smoother, and this improves its anti-clogging characteristics.
In this document, ways to improve steel quality with anti-clogging materials are discussed and the venturi nozzle design is introduced.

2 ANTI-CLOGGING MATERIALS

2.1 Application to SEN

Table 1 shows the characteristics of anti-clogging materials evaluated in this study. Material A applied to the inner bore of SEN is a carbon-free material. Since it has reduced thermal spalling resistance due to low thermal conductivity, we do not use it in the port area which can easily cool prior to start cast.
Material B, a low carbon content material is applied in the ports. Although alumina adhesion of material B is higher than that of material A, the amount of adhesion is considerably less than the conventional body material.
The location of these materials in the SEN is shown in Figure 1.

Table 1. Chemical composition and physical properties

		Anti-clogging materials	
	Body	A (Inner)	B (Ports)
C Al_2O_3 SiO_2	27.0 46.0 25.0	- 63.0 35.0	11.0 45.3 41.1
Apparent porosity (%) Bulk density ($g \cdot cc^{-1}$) Modulus of rupture (MPa) Thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$)	13.0 2.30 12.0 17.8	20.2 2.51 10.9 2.7	16.9 2.47 8.7 7.1

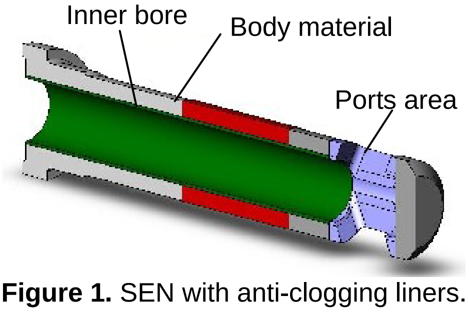

Figure 1. SEN with anti-clogging liners.

2.2 Anti-Clogging Mechanism

Figure 2 shows the anti-clogging mechanism. In the case of the body material, the surface loses smoothness due to removal of carbon and reduction of silica. Since the anti-clogging mixes have little or no carbon, smoothness and a dense layer is maintained during casting and alumina does not adhere.
Additionally, the low thermal conductivity non-carbon material, does not act to cool the steel, preventing skulling and deposition.

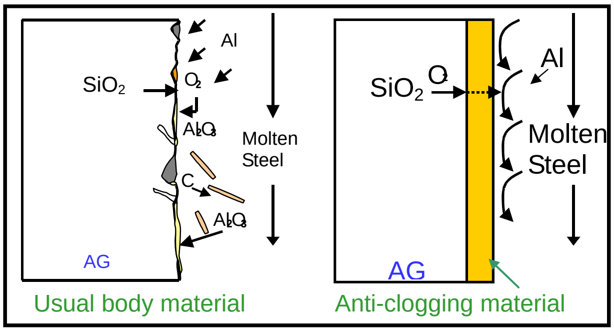

Figure 2. Adhesion prevention mechanism.

2.3 Field Test Results

Figure 3 shows microscopic photos of the texture of each material after use. The body material composed of Al_2O_3-SiO_2-C, SiO_2 reacted with carbon on the hot face, and the smoothness of the surface was lost.
With the application of material A, some reaction occurred between the body material and material A. However, material A has not reacted at the hot face, and the smoothness of surface was retained.

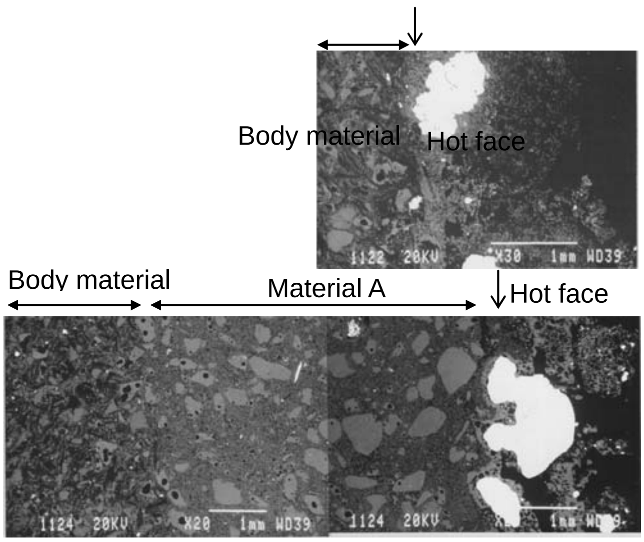

Figure 3. Microstructure of conventional and improved material.

3 INFLUENCE OF SEN PREHEAT TEMPERATURE ON ALUMINA ADHESION

Anti-clogging materials have been applied at many users and achieve good results. However, under some operating conditions, alumina adhesion is still found.

The presumption was that alumina adhesion on the anti-clogging material is affected by the preheat temperature of the refractory.

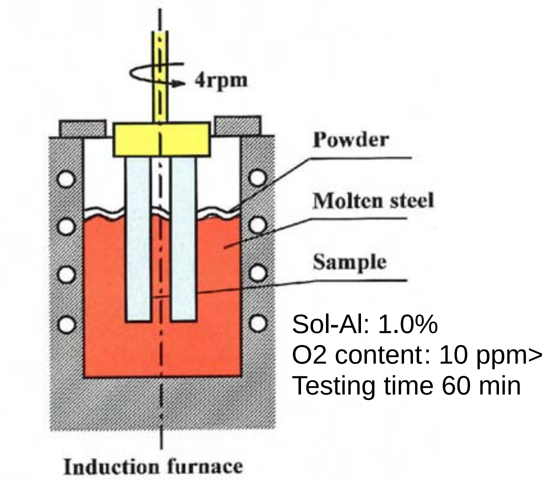

Figure 4. Alumina adhesion testing apparatus.

3.1 Experimental Apparatus and Method

Figure 4 shows the layout of the alumina adhesion test apparatus. To check the influence of preheat temperature, samples were heated by burner before dipping into molten steel. Preheating temperatures were 600°C, 800°C, 1,000°C and 1,200°C.
Samples were rotated in the molten steel which included aluminum, at about 1,550°C for 60 min. The reacting aluminum adhered to the surface of the samples as Al_2O_3.

3.2 Results of Lab Test

Figure 5 shows the samples after lab test. Figure 6 shows the correlation of pre-heat temperature and amount of alumina adhesion. It was confirmed that the higher the preheat temperature, the less the alumina adhesion.
It is believed that the low temperature surface starts and progresses the alumina deposition process more rapidly. Once deposition starts, the anti-clogging layer is rendered ineffective.
Therefore, it is important to reduce alumina deposition at start cast by using a properly preheated SEN and shortening the loss time (time from off preheat to start cast).

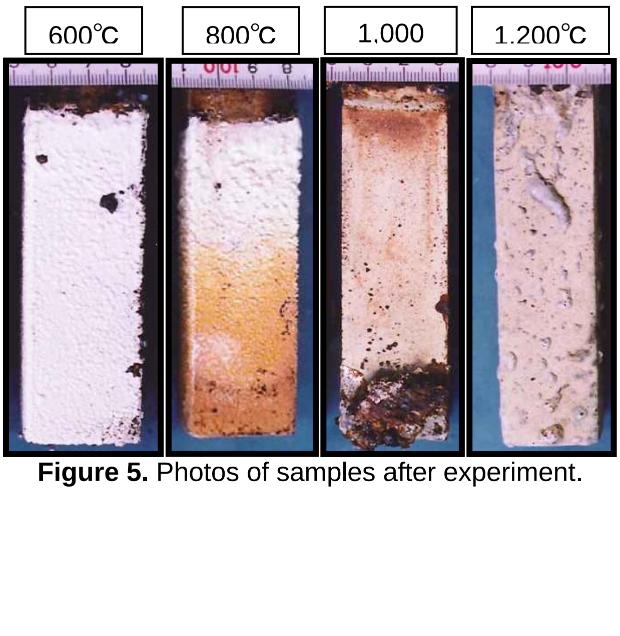

Figure 5. Photos of samples after experiment.

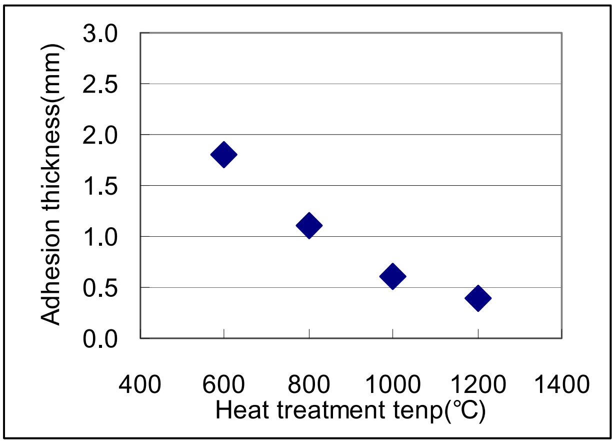

Figure 6. Correlation of pre-heat temperature and alumina adhesion.

3.3 Results of Field Testing

Figure 7 shows the correlation of preheating time and the amount of alumina adhesion. The preheat curve is shown by the red line. It was confirmed that adhesion reduced with higher temperature, but it also shows that longer preheat also reduces adhesion. It is believed that the loss time factor (length of time from end of preheat to start cast) plays a significant role in this process.

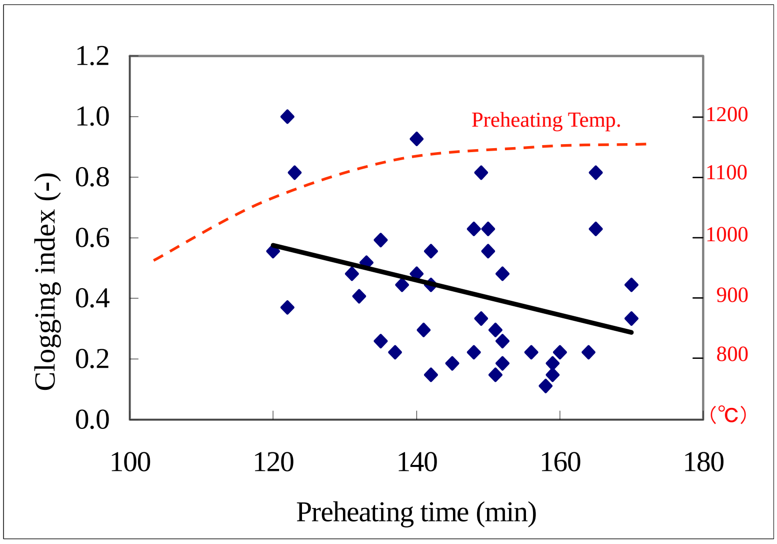

Figure 7. Correlation of preheat time and amount of adhesion.

4 VENTURI NOZZLE

As already discussed, alumina adhesion in the inner bore of the SEN can be reduced by applying anti-clogging materials. However, biased flow generated by slide gate throttling creates conditions of low flow which can cause localized adhesion. It is therefore important to stabilize the flow of molten steel in the SEN to produce high quality steel.

The venturi effect is the reduction in fluid pressure that results when a fluid flows through a reduction in flow cross-section. It is possible to make the uniform flow in the SEN by applying this principle.

4.1 CFD Analysis of Venturi Nozzle

Figure 8 shows the flow velocity results of CFD (Computational Fluid Dynamics) calculations of a straight type nozzle versus a venturi type. The mold size is 1500 x 240 mm, the casting speed is 2.2 m·min^{-1} in this calculation. For this SEN design, the reversing flow to the meniscus line is strong in the venturi type while the straight SEN has a strong downward flow.
The "pressure at the mold surface results" of CFD are shown in Figure 9. In the straight SEN, pressure of mold surface is clearly different right and left, while the venturi SEN is more balanced. In addition, the absolute value of pressure is greater for the straight SEN. The higher the pressure at the mold surface, the greater the fluctuation of the meniscus line.

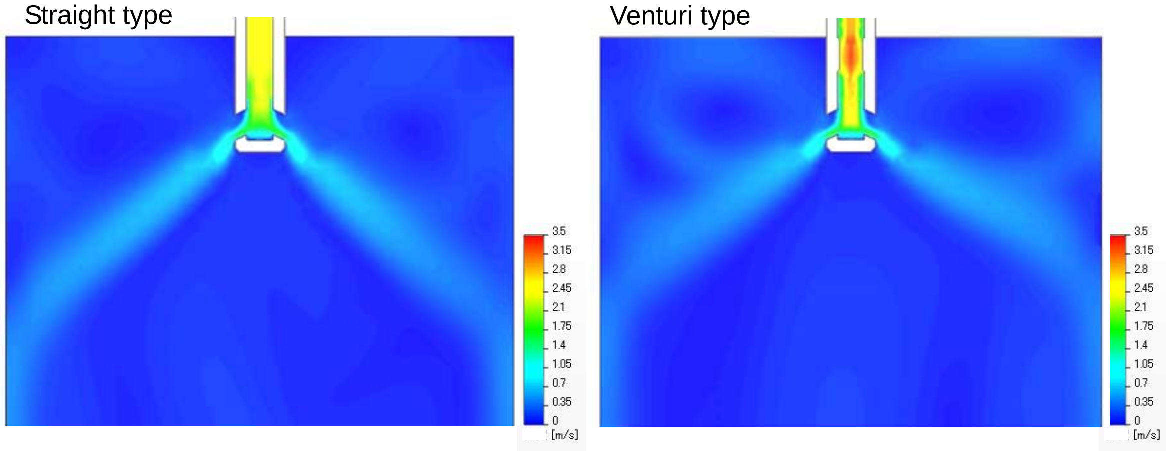

Figure 8. Flow velocity results of CFD analysis.

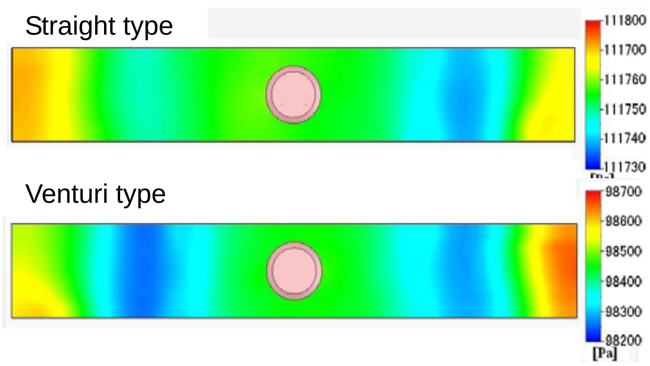

Figure 9. Pressure results at mold surface of CFD analysis.

4.2 Water Model of Venturi Nozzle

Water modelling is an effective method of simulating the flow of molten steel in the mold. The flow velocities from the ports of the SEN's (straight and venturi type) are measured in the water model.
Figure 10 shows the water model setup. The opening ratio of the slide gate is set at 80% to generate a biased flow in the SEN. The flow velocities of each port are measured at 5 points by a physical propeller current meter.
The measurement results of flow velocity are shown in Figure 11. The number shown is the average flow velocity at each point (cm·sec^{-1}), while a bigger size of circle signifies faster flow speed.

In the straight SEN, it was confirmed that there was a big difference in flow velocity in each corner of both ports. In a venturi type, the flow velocity is homogenized within a port, while the flow from right and left port is also more uniform. It is clear that the biased flow generated by slide gate throttling is suppressed with the venturi shape in the inner bore of the SEN.

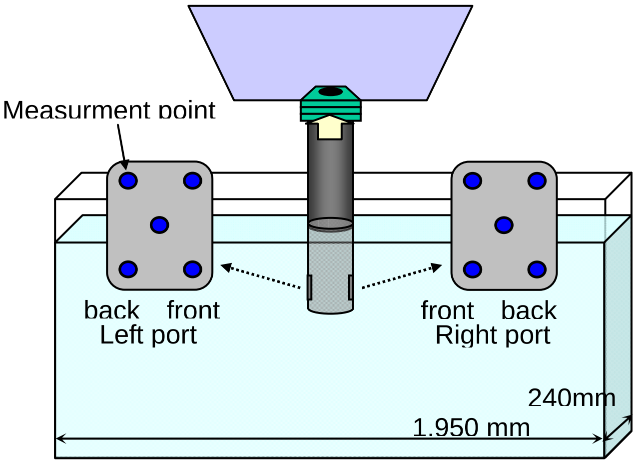

Figure 10. Water model setup.

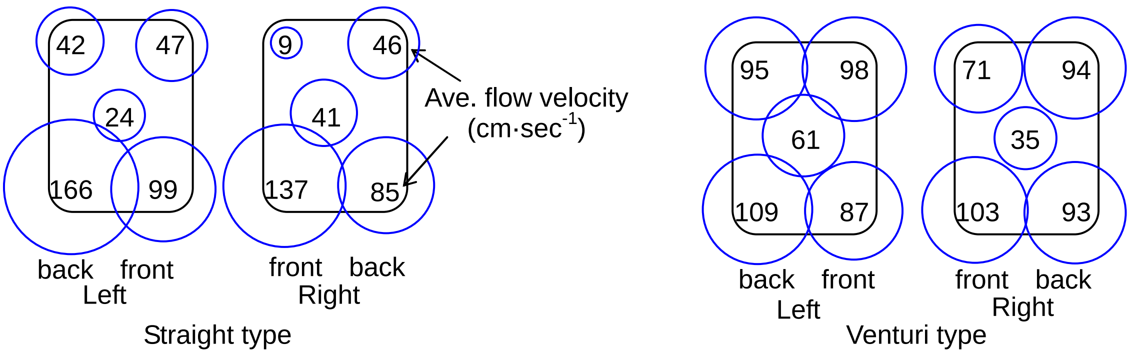

Figure 11. Result of velocity distribution at ports.

5 NEXT GENERATION VENTURI NOZZLE

The next generation Venturi nozzle was developed to achieve a more ideal molten steel flow in the mold. This nozzle removes part of the steps from a conventional venturi nozzle in order to slow the velocity in the central bore. Figure 12 shows this nozzle design.

The water model examination was done in the same manner as that previously described in section 4.2. The measurement results are shown in Figure 13. The uniformity of flow velocity at the ports is similar to the conventional venturi nozzle. However, the next generation venturi nozzle had better water model results than the conventional type in meniscus stability.

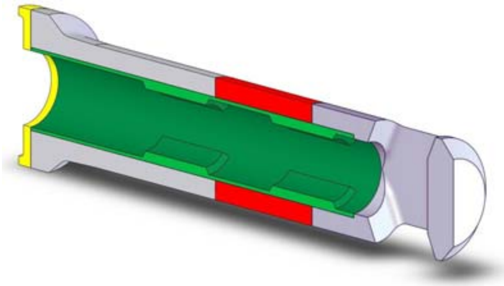

Figure 12. Next generation Venturi Nozzle.

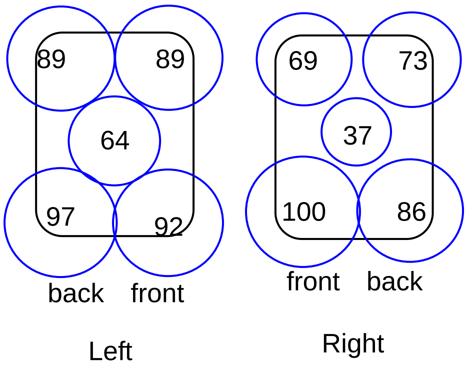

Figure 13. Velocity distribution at ports of next generation Venturi Type.

6 RESULTS OF FIELD TESTING

Figure 14 shows the samples after used of Next Generation Venturi Type nozzle. It was confirmed that Alumina adhesion reduced compare with conventional nozzle. The inner surface of sample has not crack、and venturi form is held normal state.

Figure 14. Result of next generation Venturi Type.

7 CONCLUSION

Non-carbon anti-clogging materiall can prevent alumina deposition, but the effect is improved with high temperature SEN preheat and reduced loss time at start cast. In addition, the next generation venturi nozzle is effective in reducing biased flow and improving meniscus stability.The combination of the next generation venturi design with anti-clogging materials has been very successful in improving steel quality.

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