Effect of Annular Step SEN with Carbon Free Liner in Reducing Alumina Clogging Problem at BlueScope Steel

Hiroyasu NIITSUMA[*1] Masanori OGATA[*2]
Ian McLENNAN[*3] Paul CASSAR[*4] Mark CAMPLIN[*4]

Abstract

At the No. 2 and No. 3 slab casters at Port Kembla Steel Works of BlueScope Steel in Australia, there was a strong drive to improve the steel flow pattern and anti-clogging countermeasures in order to improve the steel quality. By the application of the Annular Step SEN with a carbon free liner combined with multi layer porous upper nozzle, alumina clogging incidence in the SEN was drastically decreased. In order to achieve stable casting with less alumina clogging incidents, it is very important to have a synergy effect of appropriate Ar gas practice, configuration of the SEN and materials of the SEN.

1. Introduction

In the continuous casting process of steel, the Submerged Entry Nozzle (SEN) is one of the most important functional refractory items which influence the quality of the cast steel. Even though SEN are designed to provide an ideal flow pattern of liquid steel in the mold, there are two well known factors that cause deterioration in the flow pattern in actual casting. One is the generation of biased flow around the flow control mechanisms such as the sliding gate section, the other one is the alumina clogging in the SEN bore (Fig. 1). The first one causes not only biased flow in the SEN bore but also unbalanced outgoing flow from the outlet ports[1]. The latter often causes excessive downward steel flow in the mold which results in the increase of inclusions[2].

In order to solve such biased flow problems, we have developed unique designs of SEN such as Annular Step SEN[1] and Mogul SEN[3] (Fig. 2). The Annular Step SEN has circumferential annular steps in the bore, where the number of steps is two or more in general. On the other hand, the Mogul SEN has many spherical projections on the surface of the bore, which looks like mogul ski run. Service use of the application of these unique design SENs gave many good effects as a result of suppressing the biased flow, such as the homogenization of the temperature distribution in the mold[1], an increase of the casting speed thanks to much more stable mold level[4], a decrease in slabs cracking[5], a decrease in gas bubble related defects[6], and so on. However, the effects on suppressing the biased flow by the introduction of projections on the surface of the bore are weakened when the basins between the projections are filled by alumina clogging. Therefore, it is very important to utilize some

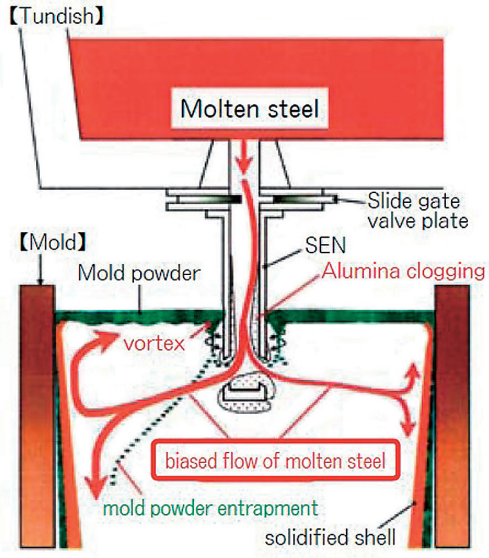


Fig. 1 Generation of biased flow at flow control mechanism and poor flow pattern in the mold caused by alumina clogging.

*1 Managing Research Engineer, Shaped Refractories R&D Group, Research Center
*2 Dr. Sci., Manager, Shaped Refractories R&D Group, Research Center
*3 Shinagawa Refractories Australasia Pty Ltd
*4 BlueScope Steel Ltd

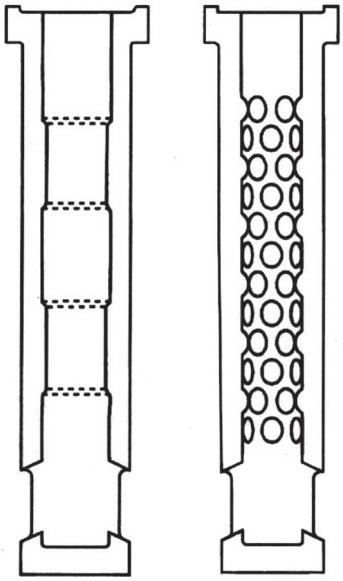


Fig. 2 Schematic drawings of annular step SEN (left) and mogul SEN (right).

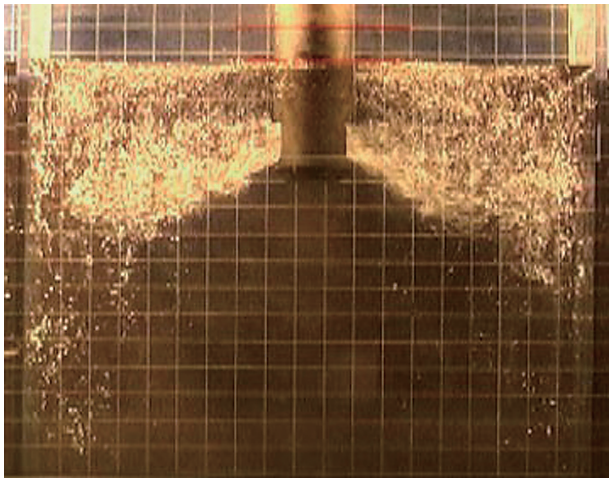


Fig. 3 Water simulation test of annular step SEN for BlueScope steel.

anti alumina clogging technique together with these SEN designs in order to obtain a long superior projection performance life.

In No. 2 and 3 slab casters at Port Kembla Steel Works of BlueScope Steel in Australia, even though the sequence length of TD were not affected by alumina clogging of the SEN thanks to the use of the quick SEN change system, the requirement of improving the steel flow pattern and anti-clogging countermeasures was strong in order to improve the steel quality. A photo of a water model test of the Annular Step SEN which was designed to suit the casting condition of the No. 2 and 3 casters is shown in Fig. 3. Excellent flow pattern was recognized such as less biased flow, stable meniscus level, and suppressed downward flow in the narrow face ends of the mold. SENs of this annular step design were tested, however, there was almost no change from the view point of alumina clogging prevention compared to the conventional straight bore SENs. The reason why there was almost no change, we thought, was the effect of Ar gas blowing practice. At that time, Ar gas was blown through small multi holes installed in the upper nozzle and the upper plate. We thought the effectiveness of Ar gas blowing of this practice was insufficient to suppress the alumina clogging due to the possible gas leakage and unstable gas bubble formation.

In order to solve this issue, Ar gas practice was changed from multi hole blowing method to porous bubbling method[7]. A porous upper nozzle was introduced. After this change, Annular Step SENs with carbon free liners were again tested, and then, there was a significant improvement in reducing alumina clogging[8]. So, we recognized how important it is to get the combined effect of three techniques such as appropriate Ar gas blowing practice, SEN configuration and SEN material in order to achieve stable casting without alumina clogging issues.

2. Ar Gas Blowing Method and Annular Step SEN

Local turbulences of steel flow generated by the steps or spherical projections have important role in suppressing the biased flow in the inner bore of the Annular Step SEN or Mogul SEN. Fig. 4 shows schematic images of the movement of steel flow generated by the projections. Although the distribution of steel flow in the whole bore of Annular Step and Mogul SENs is good, there are local turbulences around at the projections[3]. If Ar gas bubbles are efficiently stirred by these local turbulences in the bore, it should improve the Ar gas blowing effect of suppressing alumina clogging. In a previous water model simulation test study, it was reported that Ar gas bubbles coming out of an Annular Step SEN were smaller than those coming out of a straight bore SEN[1]. This phenomenon was thought to be a proof that bubbles in the Annular Step SEN were well stirred in the bore by the presence of steps/projections.

In order for the Ar gas bubbles to be stirred effectively by the projections, the gas bubbles must descend close to the surface of the bore. Fig. 5 shows the behavior of gas bubbles as determined by fluid model calculation. As shown in Fig. 5, gas bubbles injected through the upper nozzle will not descend along the surface of the bore because they tend to descend through the center area

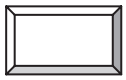
	Round Mogul	Inverted teardrop Mogul	Annular Step
Plane Figure			
Longitudinal Cross Section			
Even flow effect	◎	○	○
Throughput keeping	△	◎	○
Effect of projections in Submerged area			

Fig. 4 Difference in flow pattern on inner structure.

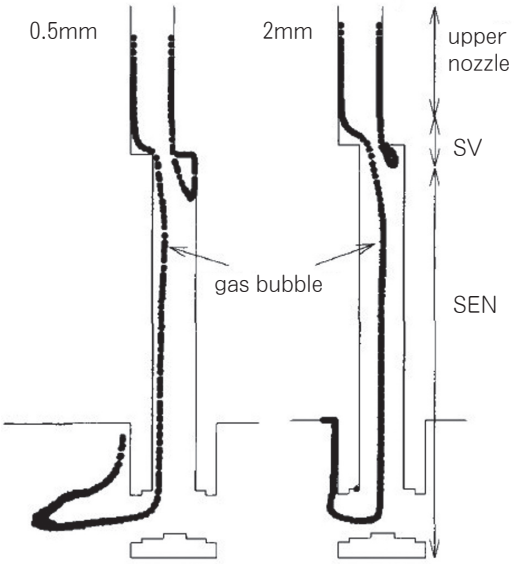


Fig. 5 Gas bubble behavior from upper nozzle to SEN.

of the SEN bore below the flow control zone[9]. Another finding of this calculation is that small bubbles should be more effective in preventing alumina clogging because large bubbles have a tendency to move in to the center area of the bore quickly. On the other hand, small bubbles may cause bubble relating defects in the slab because they cannot float quickly in the mold. Therefore, it is very important to control Ar gas bubbles to have appropriate sizes in order to achieve both the improvement of slab quality and the reduction of alumina clogging. The Annular Step SEN and Mogul SEN should perform well in reducing SEN alumina clogging when combined with suitable Ar gas blowing.

3. Application of Carbon Free Liner

During casting, the inside of the SEN is exposed to high temperature liquid steel in a reducing atmosphere. Under this condition, carbon in the microstructure of SEN will move out of the SEN by the reaction with other components as follows;

$$C(s) + SiO_2(s) \rightarrow CO(g) + SiO(g)$$

This reaction causes the SEN microstructure to deteriorate. In addition, it is known that Al_2O_3 is formed by the reaction between dissolved Al in the liquid steel and CO and SiO gases generated by the reaction mentioned above. After such reactions between CO gas and dissolved Al in steel, the inner surface of the SEN has tendency to have heavy alumina adhesion, so, it is reasonable to suppress the gasification of the carbon in the SEN microstructure for the purpose of preventing alumina clogging.

Carbon free liner materials were developed to eliminate the root causes and to suppress these reactions[2]. Because the material does not contain carbon, there is

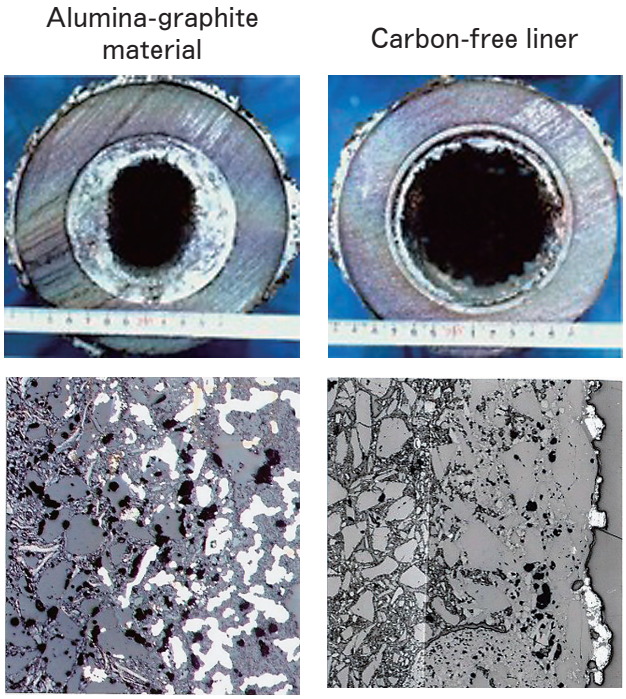


Fig. 6 Difference of alumina clogging conditions between the normal AG (alumina・graphite) SEN and the non carbon liner SEN.

no CO gas generation, which oxidizes Al in liquid steel. Furthermore, adhesion of alumina inclusions in liquid steel to the surface of the carbon free liner is also suppressed because the carbon free liner has smoother surface than carbon containing materials, of which the surface becomes porous and rough as a result of decarburization.

In Fig. 6, cut sections and micro textures of a conventional SEN with alumina-graphite material and a new SEN with carbon free liner after casting aluminum killed steel are compared. In the microtexture of the alumina-graphite material, a lot of metal particles which had penetrated into the decarburized layer were observed and the boundary between the refractory and adhering alumina could not be clearly recognized. On the other hand, in the micro-texture of the carbon free liner, there is seen a thin but dense reaction layer on the surface, which might have been formed by the reaction between the refractory and components and/or inclusions in the liquid steel. Such texture generally shows less alumina adhesion due to being well wet by liquid steel[10].

We have had many successes in the application of carbon free liners to Annular Step SEN.

4. Actual Results at BlueScope Steel

In No. 2 and 3 slab casters at Port Kembla Steel Works of BlueScope Steel, Annular Step SENs with carbon free liner were put through actual caster trials in the combination with multi layer porous upper nozzles. In Fig. 7, the thicknesses of adhering alumina layer in the bore at the powder line were compared between tested SENs and conventional SENs. All through the trial, the trial SEN showed less clogging than the ordinary SENs used in the other strand at the same time. The cut sections of the two types of SENs are compared in Fig. 8. The white 5mm thick ring in the trial SEN is carbon free material. There was almost no alumina adhesion in this SEN.

After this trial, usage of Annular Step SENs was increased step by step and they are used as ordinary SEN currently[8]. Recent measurement data of alumina

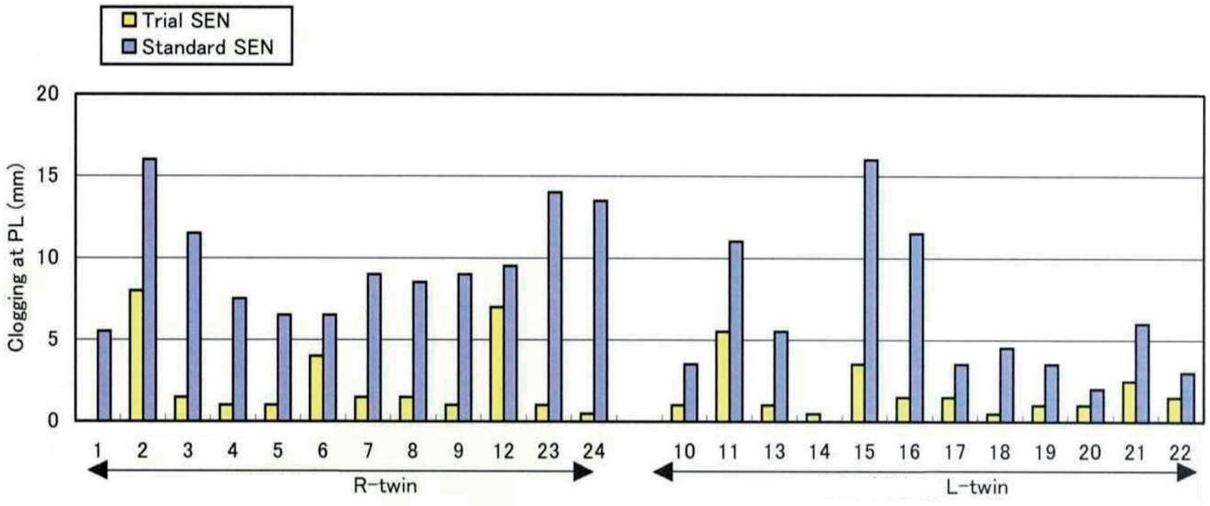


Fig. 7 Test result of annular step and non carbon liner SEN in BlueScope Steel.

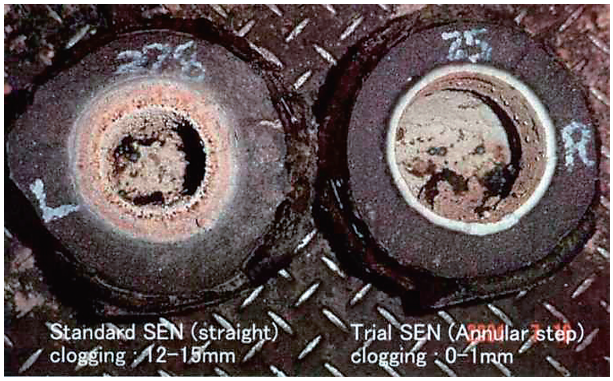


Fig. 8 Comparison of alumina clogging at powder line.

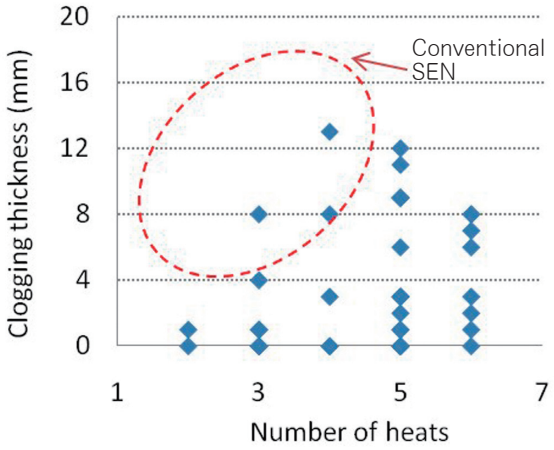


Fig. 9 The amount of clogging in inner bore.

adhesion is shown in Fig. 9. As a result of the reduction of alumina adhesion, the frequency of emergency low heat SEN changes has been decreased drastically. This has helped in reducing the refractory costs by the increase of SEN life and the decrease of extra SENs used for emergency change. In addition, as shown in Fig. 10, the frequency of casting slow down incidents caused by alumina clogging have been decreased by a half, resulting in more stable operations.

5. Conclusion

By the application of the Annular Step SEN with carbon free liner combined with a multi layer porous upper nozzle, SEN alumina clogging incidents were drastically decreased at BlueScope Steel. The synergetic effect of appropriate Ar gas practice, configuration of the SEN and material of the SEN are critical to achieving stable casting with less alumina clogging incidents.

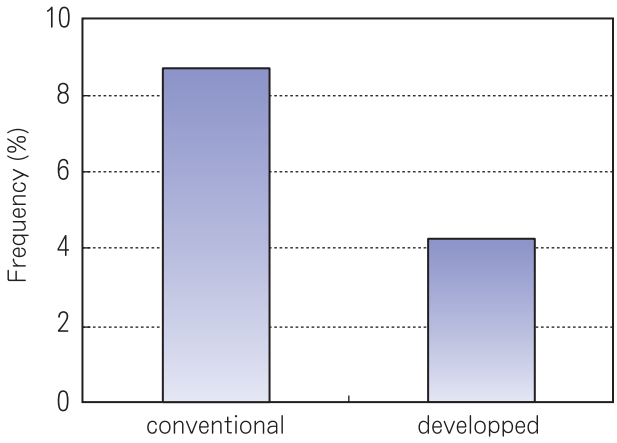


Fig. 10 Comparison of the frequencies of the casting slow down incidents caused by alumina clogging.

References

1) N. Hiroki, A. Takahashi, Y. Namba, N. Tsukamoto, Y. Kurashina, K. Yanagawa : Shinagawa Technical Report **36**, 75 1993
2) N. Tsukamoto, M. Takai, O. Nomura, M. Ogata, W. Lin : Shinagawa Technical Report **44**, 27 2001
3) M. Nakamura, S. Inoue, T. Horiuchi: Shinagawa Technical Report **49**, 59 2006
4) T. Matsunaga, K. Kanamaru, M. Nakamura, S. Inoue, S. Shike, K. Masuda, T. Iwatsuki : Taikabutsu **59**, 81 2007
5) S. Kurasako, T. Anan, K. Yoshizawa, O. Tamura, M. Ogata, T. Matsunaga : Shinagawa Technical Report **53**, 1 2010
6) P. Colucci, M. Halloucherie, F. Leclercq, D. Verrelle, C. Schiltz, E. Iida, M. Nakamura : Shinagawa Technical Report **51**, 9 2008
7) A. Medina, T. Jaques, M. Camplin, J. Neilson: 9th Biennial Worldwide Congress on Refractories, 765 2002
8) H.Niitsuma, et al : UNITECR 2011, Proceeding 2011
9) H. Suzuki, Y. Yoshimura, M. Ogata, N. Imai : Shinagawa Technical Report **46**, 67 2003
10) R. Suzuki, et al : Shinagawa Technical Report **55** (This paper), 2012