

SHINAGAWA TECHNICAL REPORT

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品川技報

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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. 緒言

溶鋼の連続鋳造で使用される浸漬ノズルは、鋳片品質に影響を及ぼす重要な機能性耐火物の一つである。浸漬ノズルの構造はモールド内で理想的な溶鋼流動パターンが得られるように設計されるが、実際の鋳造ではその流動パターンを悪化させる2つの要因がある。ひとつは流量制御部における偏流の発生であり、もう一つは浸漬ノズルのアルミナ閉塞である (Fig. 1)。前者はノズル管内だけでなくノズルからの吐出流においても偏った流れを生じる¹⁾。後者はモールド内での偏流の原因となるだけでなく、吐出流が下向きとなり、介在物浮上に不利な流動パターンを招きやすい²⁾。

品川リフラクトリーズでは流量制御部で発生す

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

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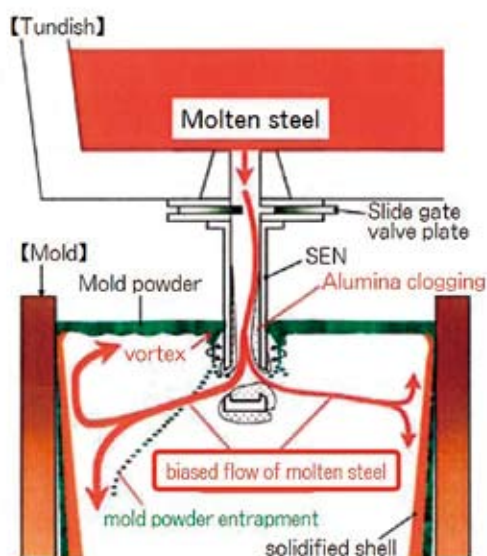


Fig. 1 Generation of biased flow at flow control mechanism and poor flow pattern in the mold caused by alumina clogging.

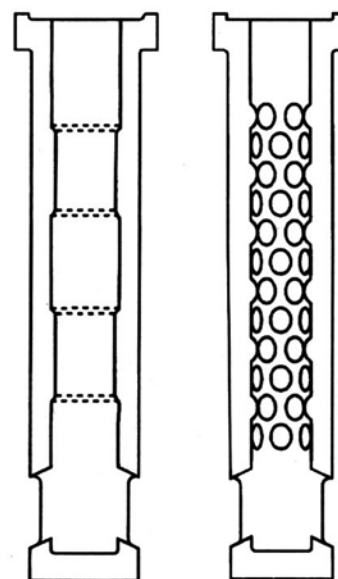


Fig. 2 Schematic drawings of annular step SEN (left) and mogul SEN (right).

る偏流防止対策として、内管に二重の環状段差突起や多数の球状突起を設けた浸漬ノズルを開発してきた (Fig. 2)。前者は段差型浸漬ノズル¹⁾、後者はモーグル型浸漬ノズル³⁾と呼ばれる。これらの新形状浸漬ノズルを適用することで実際にモールド内の偏流が抑制され、モールド内温度分布の均一化¹⁾、湯面変動の低減による高速 casting⁴⁾、鋳片割れの減少⁵⁾、気泡性欠陥の低減⁶⁾など、さまざまな成果が得られてきた。しかしながら、内管にアルミナが付着して突起の間が埋もれてしまうと、突起構造の効果が失われてしまうという課題があった。すなわち、偏流防止効果を持続して発揮させるためには、内管突起構造とアルミナ閉塞対策とを組み合わせることが重要である。

BlueScope Steel, Port Kembla製鉄所のNo. 2, 3スラブ連铸機では、浸漬ノズル迅速交換装置の採用によりノズル閉塞による連々数の制約はなかったものの、鋼製品の品質を向上するうえでモールド内溶鋼流動パターンの改善と閉塞対策は重要なテーマであった。No. 2, 3連铸機の铸造条件に合わせて設計された段差型ノズルによる水モデル実験の様子をFig. 3に示す。偏流が抑制され、湯面変動が少なく、モールド短辺から深部への吐

outlet ports¹⁾。The latter often causes excessive downward steel flow in the mold which results in the increase of inclusions²⁾。

In order to solve such biased flow problems, we have developed unique designs of SEN such as Annular Step SEN¹⁾ and Mogul SEN³⁾ (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 mold¹⁾, an increase of the casting speed thanks to much more stable mold level⁴⁾, a decrease in slabs cracking⁵⁾, a decrease in gas bubble related defects⁶⁾, 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

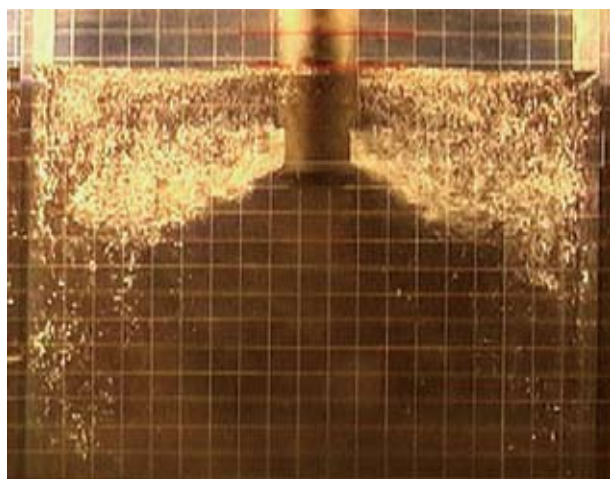


Fig. 3 Water simulation test of annular step SEN for BlueScope steel.

出流の潜り込みも抑制された流動パターンが実現されている。この段差型ノズルについて中量テストを行ったが、閉塞の点で通常の内管ストレート型ノズルに対して効果が認められなかった。当時、Arガス吹きは上ノズルと上プレートから細管方式で行っていた。この方式ではガスリークが発生しやすく、ガス吹きが安定していなかった。

そこでTD上ノズルをポーラスタイプの多層構成ガス吹上ノズルに変更した⁷⁾。この条件で内管にノンカーボン材を配置した段差型浸漬ノズルをテストした結果、通常の内管ストレート型ノズルと比べて顕著な閉塞防止効果が認められた⁸⁾。すなわち、ノズル閉塞が抑制された安定した铸造を実現するためには、Arガス吹き方式、ノズルの構造、ノズルの材質の3つの点で相乗効果を発揮させることが重要である。

2. Arガス吹き方式と段差型ノズル

段差型ノズルやモーグル型ノズルの内管では、流量制御部で発生した偏流状態を解消するうえで内管の突起位置で発生する局所的な乱流が重要な役割を果たしている。Fig. 4に突起付近における流れの変化を模式的に示す。内管突起をもつ浸漬ノズルでは、内管全体としては流速の偏りが少ない流れを提供するが、ノズル壁面の突起位置では局所的な乱流が発生する³⁾。この乱流によってAr

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 method⁷⁾. 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 clogging⁸⁾. 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.

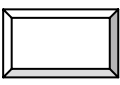
	Round Mogul	Inverted teardrop Mogul	Annular Step
Plane Figure			
Longitudinal Cross Section			
Even flow effect	◎	○	○
Throughput keeping	△	◎	○
Effect of projections in Submerged area			

Fig. 4 Difference in flow pattern on inner structure.

ガス気泡が効果的に攪拌されれば、ガス吹きによる閉塞防止効果の向上が期待できる。水モデル実験においても、同じガス吹き条件において浸漬ノズルから吐出される気泡は、段差型ノズルの方が径が小さい傾向があることが報告されている¹⁾。これは段差突起によってノズル内を流下する気泡が攪拌されたためと解釈される。

ただし、内管の突起によって気泡が攪拌されるためには気泡が壁面に沿って流下する必要がある。Fig. 5に示すように、流体計算の結果によれば、上ノズルの表面で発生した気泡は流量制御部で流れの中央に集まるため、必ずしも浸漬ノズルの壁面に沿って流下しない⁹⁾。この場合、径の大きな気泡ほど流れの中央に集まりやすいため、ノズル閉塞防止の点では径の小さな気泡を吹き込んだ方が効果的である。一方、微細すぎる気泡はモールド内での浮上が遅く、鋼製品の気泡性欠陥の原因となる。したがって、浸漬ノズルの閉塞を効果的に防止しながら鋼品質の向上を実現するためには適度に微細な気泡でガス吹きすることが重要であり、そのような条件ではノズル内管の突起が閉

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 projections³⁾. 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 SEN¹⁾. This phenomenon was thought to be a proof that bubbles in the Annular Step SEN were well stirred in the bore by

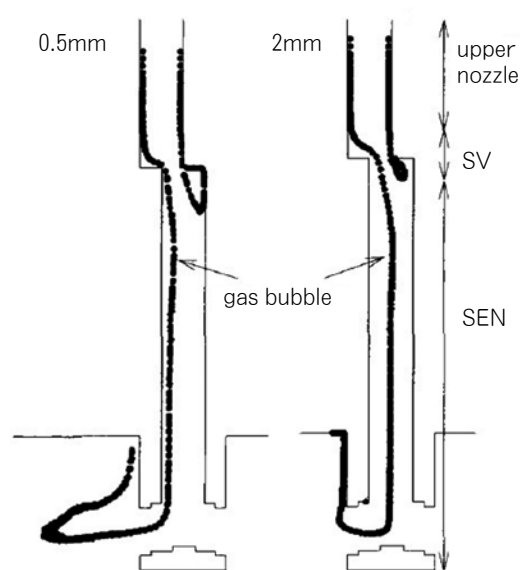
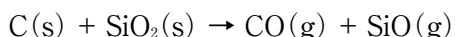


Fig. 5 Gas bubble behavior from upper nozzle to SEN.

塞防止効果を高める。

3. 内管ノンカーボン材の適用

casting中、浸漬ノズルの内部は高温・還元雰囲気
の環境下となる。このような環境下では、カー
ボンは下記の式で示されるように他成分と反応して
ガス化し、れんが組織中から失われる。



上記反応によってれんが組織が脆化すること
に加え、発生したCOガスやSiOガスは鋼中のAlと反
応して Al_2O_3 を生成することが知られている。CO
ガスと鋼中Alの反応により Al_2O_3 が生成したノズ
ル表面は、より Al_2O_3 が付着しやすくなるため、
カーボンのガス化を抑制することは、アルミナ付
着防止の観点からみても非常に重要である。

ノンカーボン質内管材は、これらの反応を根
本から抑制することを目的として開発された²⁾。
カーボン源がないために鋼中Alの酸化源となる
ガスの発生がない。また脱炭による稼働面の多孔
質化や凹凸化もないため、鋼中アルミナ介在物の
付着を防止するうえでも有利である。

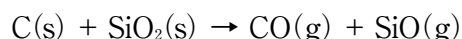
Fig. 6にアルミキルド鋼で使用した通常のAG
材ノズルと内管ノンカーボン材ノズルの稼働面組

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 sur-
face of the bore because they tend to descend
through the center area of the SEN bore below
the flow control zone⁹⁾. 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 reduc-
ing 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 com-
ponents as follows;



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 gener-
ated 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

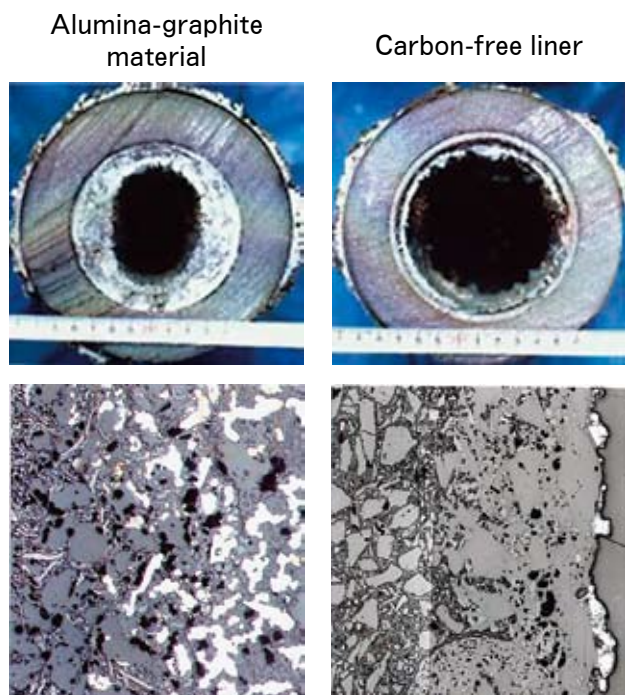


Fig. 6 Difference of alumina clogging conditions between the normal AG (alumina・graphite) SEN and the non carbon liner SEN.

織を示す。AG材では脱炭した稼働面にメタルが侵入し、耐火物とアルミナ付着物との境界があいまいになっている。一方、ノンカーボン材では稼働面が溶鋼成分や介在物と反応して、緻密で連続性の良い稼働面組織となっている。このような組織は溶鋼との濡れ性が良いため、アルミナ介在物が付着しにくい¹⁰⁾。

内管ノンカーボン材料は段差型ノズルに適用可能であり、豊富な使用実績がある。

4. BlueScope Steelでの使用結果

BlueScope Steel, Port Kembla製鉄所のNo. 2, 3スラブ連铸機で、上ノズルのArガス吹き方式をポーラス・タイプへ変更した後に、段差型・内管ノンカーボン浸漬ノズルをテストした。Fig. 7に使用後ノズルのパウダーライン位置におけるアルミナ付着厚みを示す。テストした24本すべてで、別ストランドで使用した従来の浸漬ノズルよりも付着量が少なかった。使用後ノズルの一例をFig. 8に示す。段差型ノズル(写真右)において、内管

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 reactions²⁾. Because the material does not contain carbon, there is 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 microtexture 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 steel¹⁰⁾.

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.

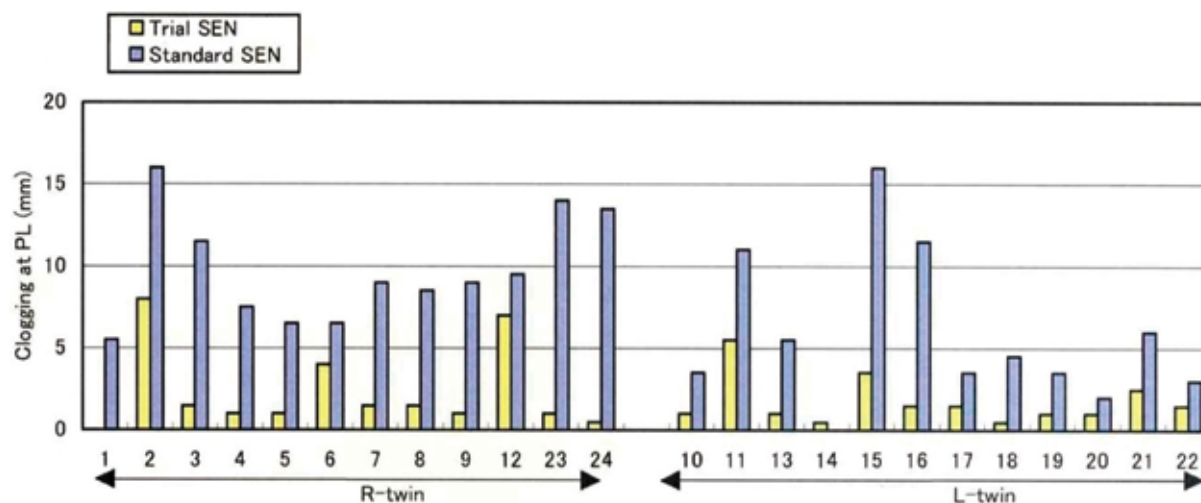


Fig. 7 Test result of annular step and non carbon liner SEN in BlueScope steel.

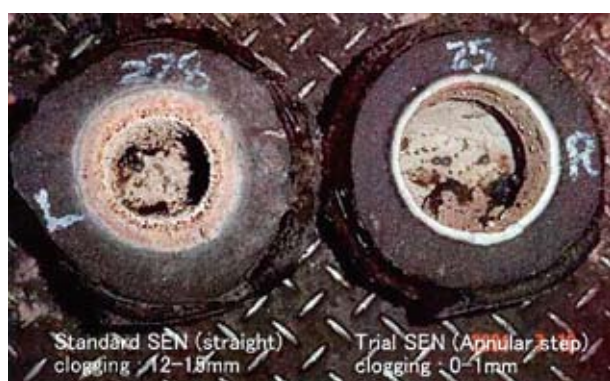


Fig. 8 Comparison of alumina clogging at powder line.

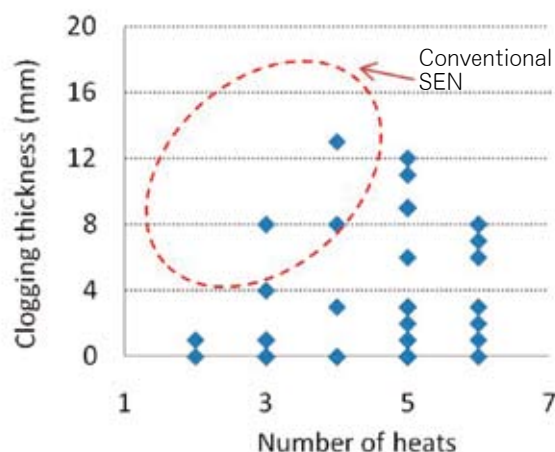


Fig. 9 The amount of clogging in inner bore.

約5mmの白色層はノンカーボン材であり、アルミナの付着はほとんど認められない。

段差型・内管ノンカーボン浸漬ノズルは、その後、段階的に使用量を拡大し、工程化した⁸⁾。最近の内管付着状況をFig. 9に示す。従来ノズルと比較して付着量が軽減し、低いヒート数で突発的にノズル交換する頻度が激減した。すなわち、操業計画通りに浸漬ノズルが使用される比率が向上し、余分な浸漬ノズルの使用分が削減された。またFig. 10に示すように、アルミナ付着による casting speed 低下のトラブルも従来品使用時と比較して半減し、安定操業に寄与することができた。

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 currently⁸⁾. Recent measurement

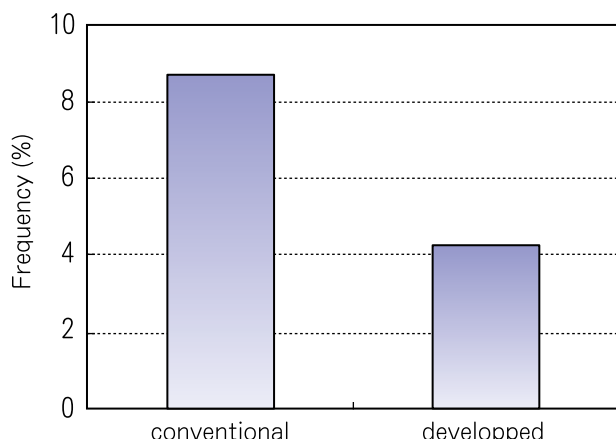


Fig. 10 Comparison of the frequencies of the casting slow down incidents caused by alumina clogging.

5. まとめ

段差型・内管ノンカーボン浸漬ノズルとポーラス・タイプ的气体吹き上ノズルをあわせて適用することによって、BlueScope Steelではアルミナ閉塞トラブルが大幅に減少した。アルミナ閉塞が発生しない安定した鋳造を実現するためには、Arガス吹き方法、浸漬ノズルの構造、浸漬ノズルの材質の相乗効果を発揮させることが非常に重要である。

data of alumina 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.

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