New Slit Plug for Ladle Refining

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Abstract

In the secondary metallurgy refining process, inert gas such as argon or nitrogen is injected into the molten steel via gas purge plugs arranged in the bottom of the ladle for stirring the liquid steel with other additives. This improves reaction efficiency and homogenizes steel temperature and chemistry.

Shinagawa Refractories Co., Ltd. has developed the new slit plug, which is designed to allow a targeted gas flow rate to be easily obtainable with structurally advanced slits, successfully provides long service life and a large amount of gas flow at many refining ladles.

1. Introduction

When molten steel is tapped into a ladle from a converter or an electric arc furnace, it is refined additionally. Inert gas such as argon or nitrogen is injected into the molten steel via gas injecting devices to stir the liquid steel with other additives in order to improve reaction efficiency and homogenize steel temperature and chemistry. Fig. 1 shows a schematic illustration of a ladle furnace (LF) which is one of the most popular processing units for secondary metallurgy refining. The ladle furnace is generally equipped with a top bubbling lance and one or more gas purge plugs arranged in the bottom of the ladle. Currently, bottom bubbling with purge plugs is the dominant method for effective stirring but in certain cases a top bubbling lance is also used independently or simultaneously. Fig. 2 shows a schematic illustration of gas purge plugs. There are two types of plugs, one is a "porous plug" that consists of gas permeable porous refractories, and the other is a "slit plug" that consists of dense refractories with slits in which gas can pass completely through. Porous plugs

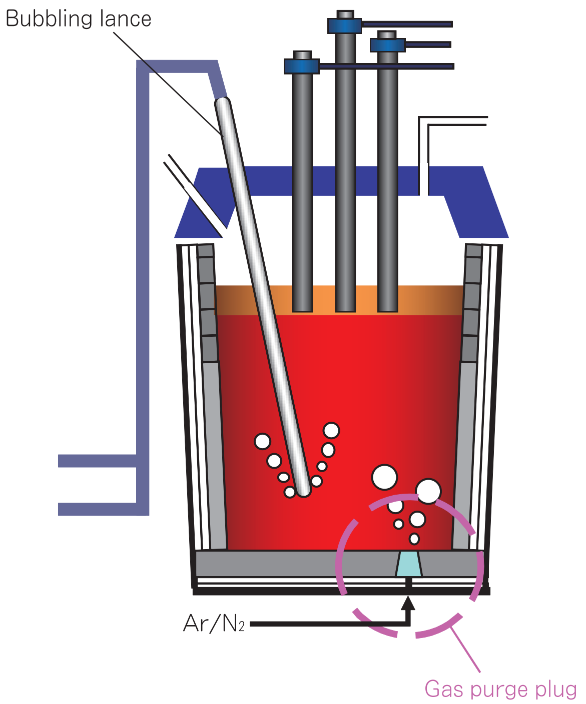

Fig. 1 Ladle furnace.

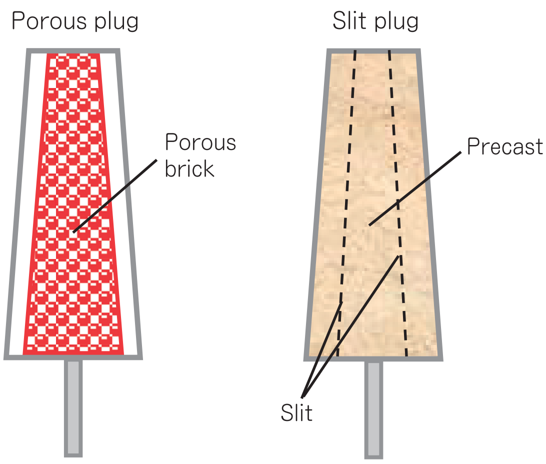

Fig. 2 Ladle gas purge plugs.

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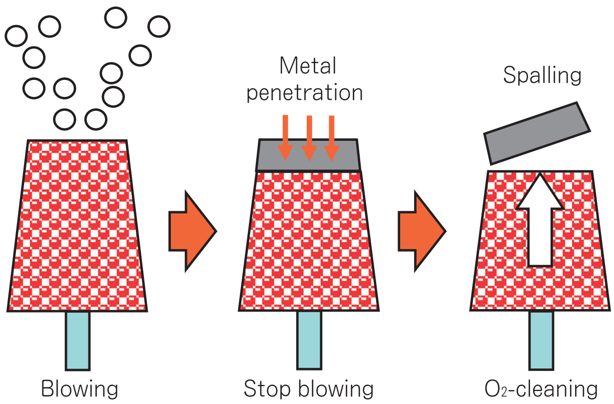


Fig. 3 Wear mechanism of porous plug.

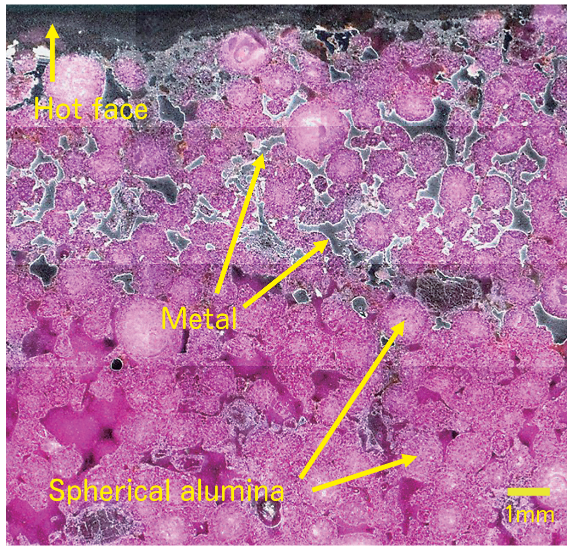


Fig. 4 Microstructure of porous plug after use.

have been widely used due to easiness of gas control and gas purging reliability since early times. Slit plugs have also been in use for years because they provide a large amount of gas flow and long service life.

Under these circumstances, Shinagawa Refractories Co., Ltd. has developed "NSP", a new slit plug which consists of high quality cast refractories and structurally advanced slits. The features and application results for some refining furnaces are described in this report.

2. Wear Mechanism of Porous Plug and its Challenges

Fig. 3 shows a schematic illustration of the wear mechanism of the porous plugs. Liquid steel tapped into the ladle from the converter or electric arc furnace is transferred to the ladle furnace station. At the refining station, argon gas is introduced via porous plugs arranged at the bottom of the ladle. During argon gas stirring, the porous plug is gradually abraded by hot flowing steel. Gas injection stops after completing steel refining and the ladle is transported to the casting stand. During this transporting process, hot steel penetrates into the open pores of porous refractories due to the ferrostatic pressure of the liquid steel and forms a clotted layer preventing gas flow as observed in Fig. 4. After casting is finished, oxygen is blown to the hot face of the porous plug from oxygen lance pipes to melt and remove the layer (called oxygen-cleaning). However, during this operation, the layer penetrated by metal on the hot face is removed but a non-penetrated layer is also removed.

During this process, as described above, porous plugs are thought to be worn by;

1) Abrasion by metal flow during gas injection
2) Penetration by molten steel into open pores

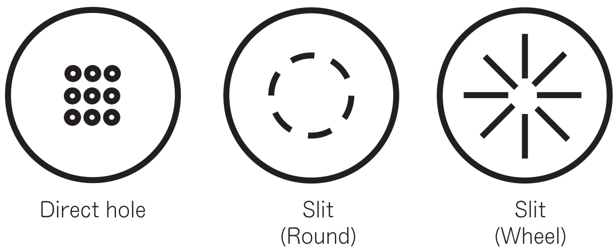


Fig. 5 Slit plug designs.

3) Corrosion during oxygen-cleaning

Currently, we have a few kinds of regular porous plugs which have been improved based on the above concepts. However, porous refractories, which consequently contain pores large enough for gas to penetrate, have a fundamental difficulty in preventing metal penetration and wear during oxygen-cleaning. For modern steel making operation, there are several improvements needed to be made in porous plugs, such as the extension of service life and a larger amount of gas transport to allow for strong stirring. Slit plugs that consist of dense precast refractories with slits resolved most of these problems and have been used widely.

3. Newly Developed NSP Slit Plug

Slit plugs are originally designed by each supplier of refractories and some typical designs are illustrated in Fig. 5. The slits in the slit plugs are formed in the manufacturing process by firing plastic films or strings at a

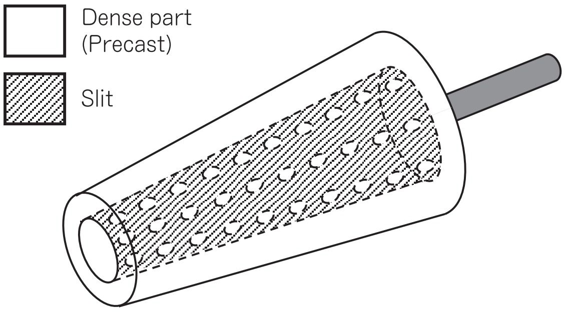
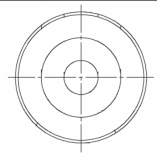
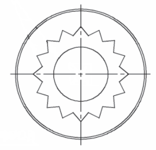
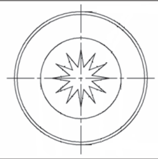


Fig. 6 Fundamental slit structure of NSP.

Table 1 Slit designs and gas flow rate of NSP

Slit design (Cross section)		Area of slit (mm^2)	Gas flow rate* (Nl/min)
Round-type		61	200～250
Star-type1		88	250～300
Star-type2 (Centered)		107	350～400

*0.1MPa, Air

specified temperature which are previously tied up in the mold before it is filled with castable. Generally dozens of slits need to be formed in these conventional slit plugs to get the targeted gas flow rate. And as the larger gas flow rate requirement increases, the number of slits increases and manufacturing difficulties also increase.

The fundamental slit structure of our newly developed "NSP" is illustrated in Fig. 6. NSP has a progressive slit-structure to improve gas bubbling performance. For example, the simplest single round type NSP consists of two cast blocks with a slit in which some dense parts are spaced at a certain interval to connect between these blocks while keeping the pathway clear. Several designs of NSPs are illustrated in Table 1. The NSP structure is designed so that the targeted gas flow rate is easily ensured without increasing production difficulty only by changing the number of slit rings or shape.

Typical refractory data of the NSP and porous plug are shown in Table 2 for comparison. Low cement alumina-spinel castable refractories are applied for the NSP to ensure the stability of volume under hot conditions in consideration of the effects on gas flow characteristics. Castables for the NSP have some good characteristics such as high thermal spalling resistance or high corrosion resistance due to dense and solid microstructure compared to that of porous plugs. A castable is selected

Table 2 Standard data of refractories for NSP and Porous Plug

Application	Slit		Porous
Code	CH18-pW4YC	CH18-AZ2	HSP20
Material	Alumina-spinel /Precast	Alumina-spinel /Precast	High alumina /Pressed
Apparent porosity (%)	23.4	21.0	23.6
Bulk density	3.01	3.03	2.84
Cold crushing strength (MPa)	75	80	52
Chemical composition (%)			
Al_2O_3	90	88	89
SiO_2	-	-	7
MgO	3	3	-
ZrO_2	-	1.5	-
Cr_2O_3	4.8	3	1.8
Slag corrosion resistance	◎	○	△
Spalling resistance	○	◎	○

◎: Superior ○: Good △: Inferior

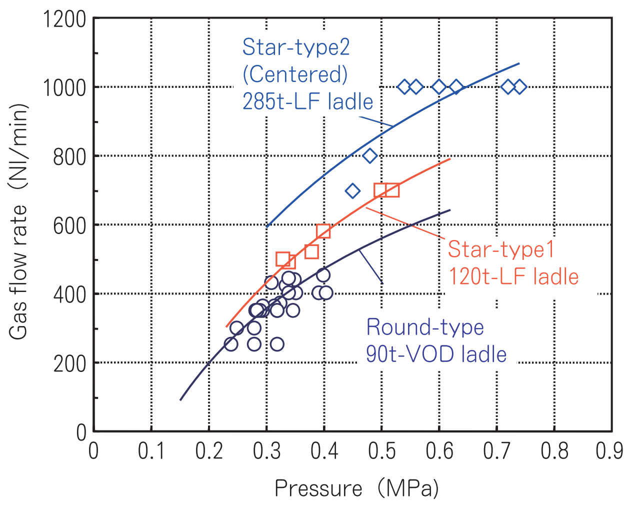


Fig. 7 Pressure-Gas flow rate curves of NSP at different sizes of refining ladles.

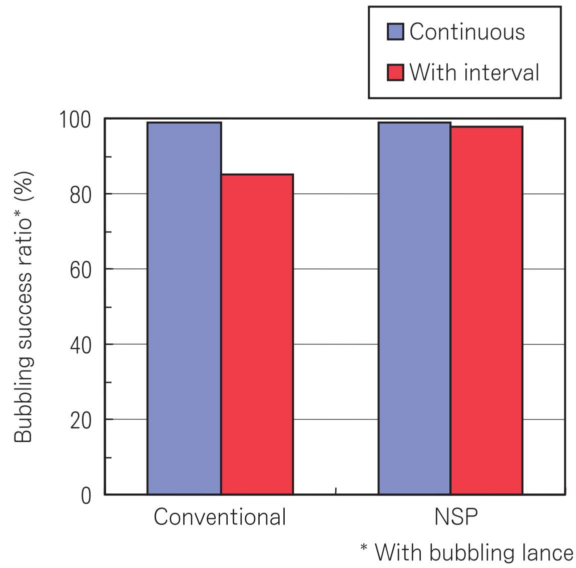


Fig. 8 Bubbling success ratio of NSP.

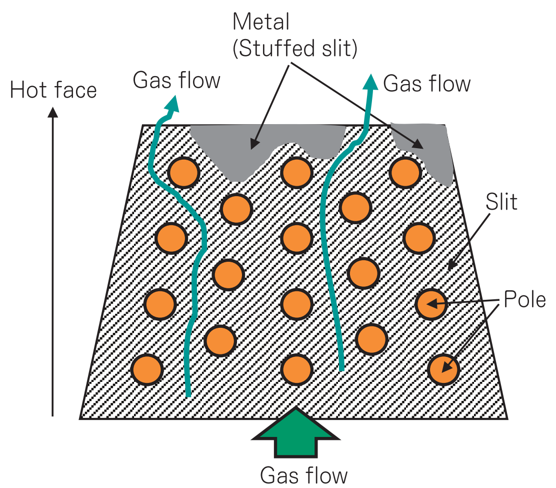


Fig. 9 Schematic illustration of NSP structure.

Table 3 Trial results of NSP at 90t-VOD ladle

	Porous	NSP (Round-type)
Life (ch)	12	15
Wear rate (mm/ch)	23	20
Bubbling success rate (%)	99	99
Max. gas flow rate (Nl/min) (at 0.6MPa)	500	700

according to the actual operation condition requirements for spalling resistance or corrosion resistance.

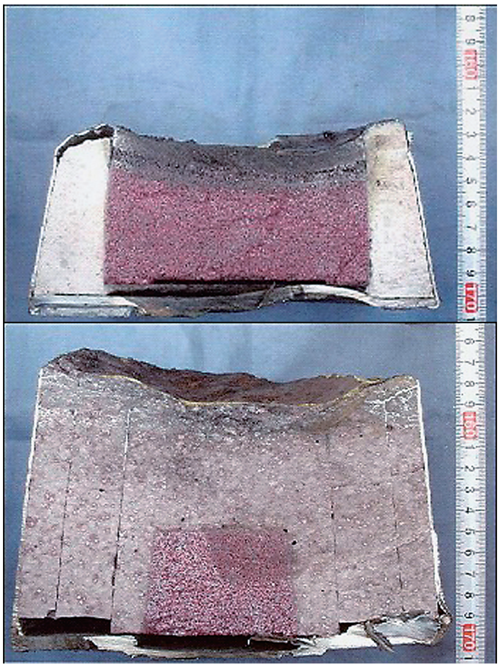
4. Application of the NSP for Refining Ladles

The gas pressure and flow rate curves of the NSPs in Table 1 which they were used in some different sizes of refining ladles are shown in Fig. 7. It was confirmed that the maximum gas flow rate was 1000NL/min with the star-type of NSP at a 285ton of ladle. The comparative results of the bubbling success ratio between a NSP and a conventional slit plug are shown in Fig. 8. The results showed 15% improvement in the bubbling success ratio of NSP compared to the conventional slit plug. Fig. 9 is a schematic illustration of the NSP structure. This continuous slit structure provides gas flow recovery performance by oxygen lance cleaning when the surface of slits clog after use from being covered with solidified steel or slag. The NSP shows stable gas flow characteristics even in an intermittent operation in which gas is blown with a long break between heats.

The performance results of a NSP in comparison with a regular type of porous plug at a 90 ton of VOD ladle in a stainless steel making plant are shown in Table 3. Cross sectional photographs of the NSP slit plug and the porous plug after use are shown in Fig. 10. The results show a 25% increase in service life under severe circumstances

Porous plug (12ch)

NSP (15ch)



*Used at 90t-VOD ladle

Fig.10 Cut surface of porous plug and NSP after use.*

Table 4 Performance records of slit plugs

Customer		Refining system	Heat size (t)	Slit-type	
				NSP	Other
Domestic	A	LF	285	○	
	B	LF	260	○	
	C	LF	255	○	
	D	LF	200	○	
	E	LF	110	○	
	F	B	80	○	
	G	B	70		○
	H	LF	15	○	
Overseas	I	LF	250	○	
	J	LF	160		○
	K	LF	150	○	
	L	B	150	○	
	M	LF	130	○	
	N	LF	120	○	
	O	B	90	○	
	P	VOD	90	○	
	Q	LF	50	○	
	R	LF	50	○	
	S	B	50		○

*B: Bubbling stand (no-arc heating)

such as long treatment time and high temperature. Also, even after blowing in 15 heats, NSP still had some service life remaining and there was no steel clogged in the slits. As for bubbling performance, the maximum gas flow rate of the NSP was increased and the bubbling success ratio also remained at higher order.

Finally, the performance records of NSPs at a lot of steel making plants are shown in Table 4. Our NSP has been used and reputed for showing the good performances both in Japan and overseas.

5. Summary

(1) The newly developed NSP slit plug is designed with an advanced slit structure to allow a targeted gas flow rate to be easily obtainable for any size of refining ladle.

(2) The NSP slit plug provided a high gas flow rate up to a maximum of 1000NL/min when used at a 285ton of LF ladle. The NSP also showed 15% improvement in bubbling success ratio in comparison with a conventional slit plug even when used for intermitted operation.

(3) The service life of a NSP used at a 90ton of VOD ladle for stainless refining was increased by 25% compared to that of a regular porous plug.