Porous Plug with "PKG" Safety Device for Protection from Molten Steel Leakage

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Abstract

Ladle refining using porous plugs is currently the most common method for improving steel quality and reducing steel production cost. Porous plugs are directly installed in the bottom part of a ladle steel shell which allow purge gas to pass through for the purpose of stirring the molten steel. They occupy the full depth of the ladle bottom lining. This makes it difficult to exterminate all the risks of molten steel leakage even if various precautions for preventing excess use of the porous plug are taken, which have been incorporated from practical experience. Porous plug with "PKG" safety device for protection from molten steel leakage is the safest plug that surely reduces the risk of molten steel leakage in case it is used beyond the limit of its serviceable life. The basic constitution of the porous plug with the PKG device and the principle for preventing molten steel leakage are described in this report.

1. Introduction

After tapping the molten steel from a primary refining furnace such as a BOF or EAF, the molten steel is subjected to further refining in a number of secondary refining furnaces in order to regulate chemical components precisely and homogenize temperature. The metallurgy processes are commonly performed in ladles. Thanks to novel technology developments, various kinds of ladle refining, which are simplified and cost-effective secondary refining methods, were put into operational services in the early 1980's in addition to vacuum degassing methods that had been the mainstream until then. The importance of stirring by a gas injection into molten steel had been recognized in ladle refining process, thus, bottom bubbling through porous plugs (as shown in Fig. 1) became popular at the same time. A porous plug is a single unit directly installed in the bottom shell of a ladle and its working surface area shows significant local wear due to the gas flow blown from the porous medium. Hence, the risk of molten steel leakage through the porous plug is considerably higher than in other area. In such a situation, every measure for ensuring safety and stable use of the ladle porous plug should be taken. "PKG" is a device that can eliminate the risk of steel leakage caused by abnormal wear of the plug. The details and concepts of the porous plug with the PKG device are described in this report.

Fig. 1　Porous plugs.

2. Porous Plug Installation Methods and Risk of Molten Steel Leakage

Fig. 2 and 3 show typical two porous plug installation methods and their assembled configurations, respectively. The first one (left side) is a built-in type porous plug set which is preassembled in a seating block. It can be installed instantly by lowering down and setting it in the ladle bottom using the overhead traveling cranes on site. The second one (right side) is an external mounting type that inserts the porous plug in the refractory lining in

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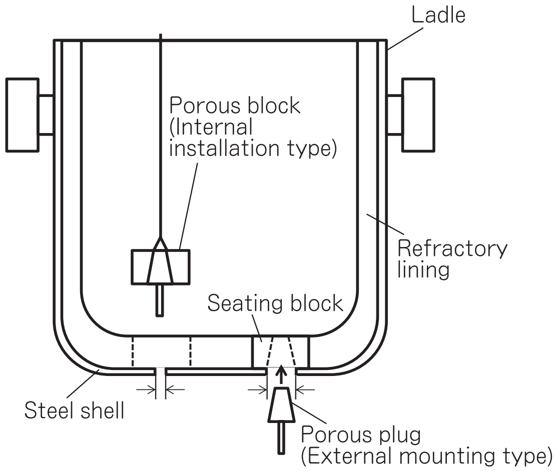


Fig. 2 Porous plug installation methods in ladles.

the ladle bottom from the outside vessel and fixes it in a determined position with fixing devices such as bayonet lock parts. These two methods are the most common.

For the built-in plug sets, the through hole size in the ladle bottom shell can be minimized since only the exact diameter of gas supplying pipes is required. On the other hand, for the external mounting type, it is necessary to be larger than the cross-section area of the plugs. The size of shell hole in the ladle bottom should be the smallest to minimize the amount of molten steel leakage since the leaking flow rate is proportional to the cross sectional area of the opening.

Especially, the possibility of a tremendous amount of leakage is a concern for the external setting plug since it has potential risk of dropping out of the plug itself. Thus, from the view point of safety, use of the preassembled plug sets is strongly recommended.

3. Plug Components and Risk of Molten Steel Leakage

It is essential to design porous plug components to minimize the outflow of leaked molten steel in case of emergency such as break-out troubles. Fig. 4 exemplifies several types of porous plug assemblies.

1) Type 1 : single core plug

A truncated porous core is positioned throughout the entire plug body. As the porous core occupies the full depth of the ladle bottom thickness, significant steel leakage according to the excessive wear of the porous core is a concern.

2) Type 2 : double-layered core plug

This plug is composed of a cylindrical porous core that is combined with a lower cubic core. Porous plugs are replaced when the shape of the porous cores at the hot surface of the plug turns from round to square as shown in Fig. 5. Using the lower cubic core as a wear indicator is the most popular method, however, the surface of the indicator is often covered by slag or metal adhesions, which may cause the operator to incorrectly judge the timing for replacing a porous plug.

3) Type 3 : porous core surrounded with sleeve

The bottom surface of the porous core is covered by a cast sleeve block. The cast block is provided with a minimum flow path corresponding to the size of gas supplying pipes. Although this structure improves the safeness against steel leakage compared to the plug

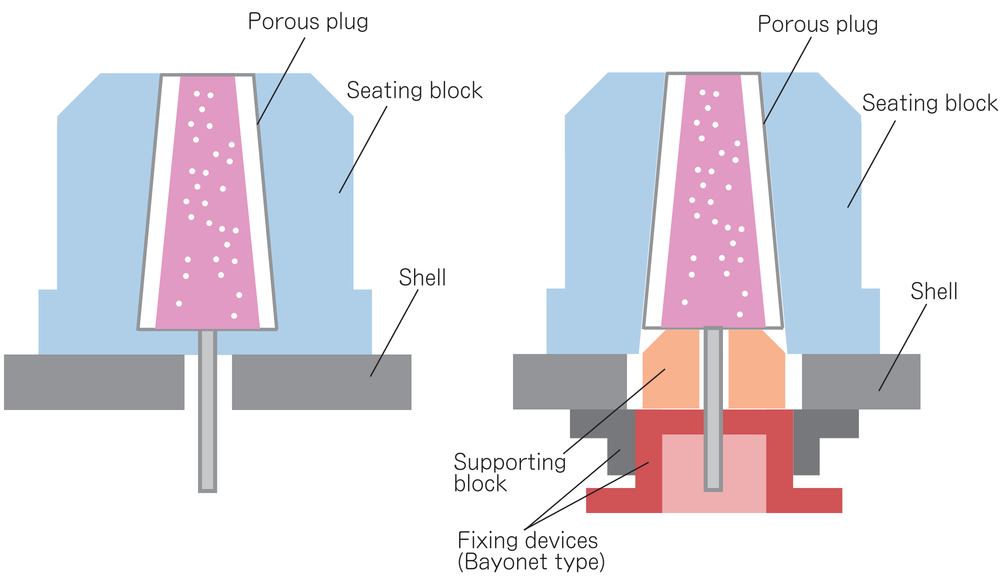
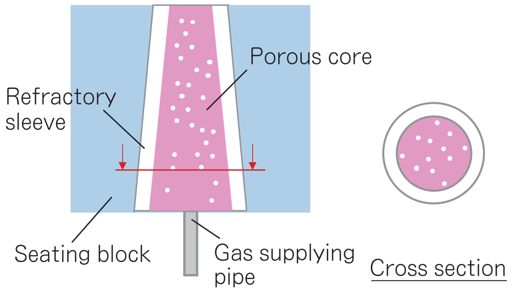
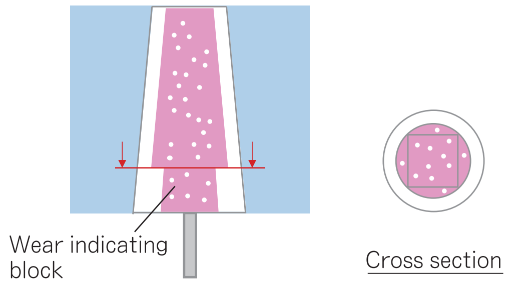
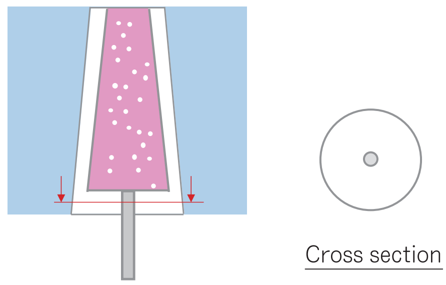
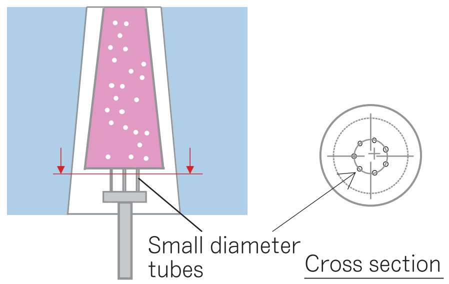


Fig. 3 Schematic diagrams of porous plug assemblies mounted on the bottom of ladles.

Types		Porous plug designs and cross sections	Risk level of leakage of molten steel*
Type 1	Single core		+++
Type 2	Double-layered core		++
Type 3	Core surrounded with the sleeve on the bottom face		++
Type 4	"PKG"		+

*(Low) + < ++ < +++ (High)

Fig. 4 Several types of porous plug assemblies considering preventions of molten steel leakage.

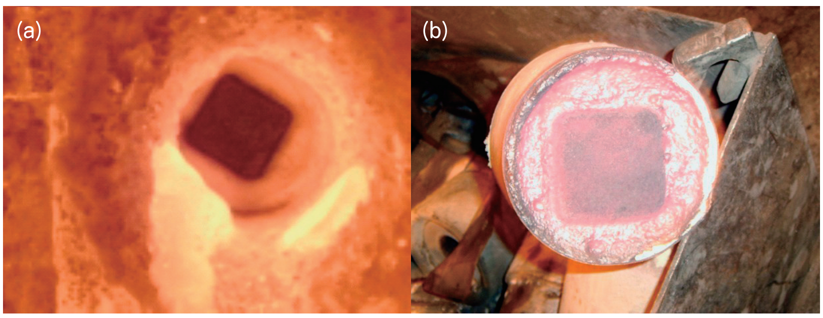


Fig. 5 Hot faces of porous plug with the square indicating block exposed: (a) on the ladle, (b) after being pulled out from the bottom.

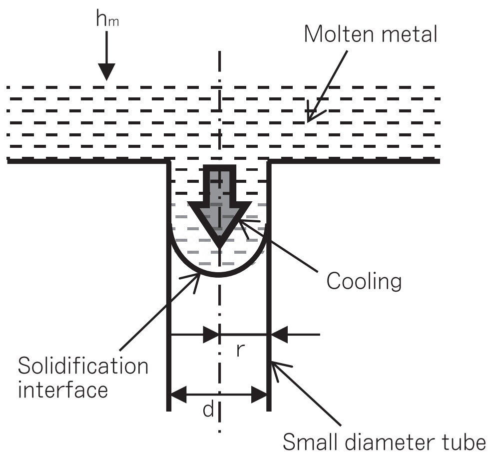


Fig. 6 Molten steel penetrating model into small diameter tubes.

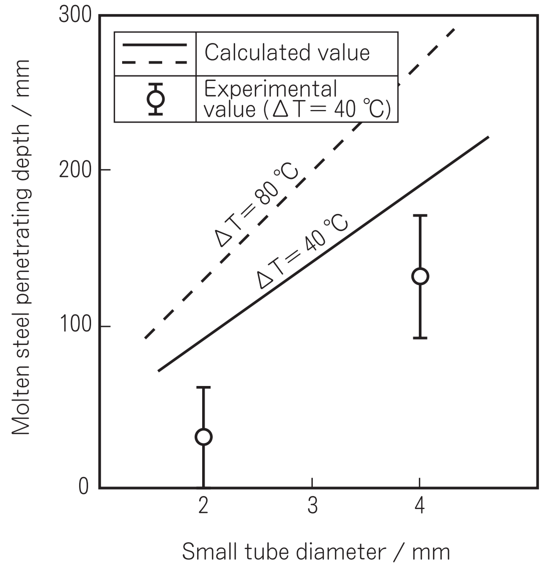


Fig. 7 Calculated and experimental results of molten steel penetration depth into small diameter tubes.

assemblies of type 1 and type 2, the potential risks still remain.

4) Type 4 : a porous plug with the PKG device

The porous plug with a PKG device is a safetyenhanced plug that has developed to reduce the risk of external molten steel leakage even when the life of the plug reaches the limit or exceeds it. The PKG structure includes multiple numbers of fine metallic tubes located behind the porous cores. The metallic tubes have dual functions as gas providers for the steel refining operation as well as molten steel solidifier for emergency steel leakage. The basic principles of designs of the PKG are described in the next chapter.

4. Basic Principles and Designs of the PKG

It is empirically known that the molten steel which penetrates into the metallic tubes solidifies at a certain depth. Yamanaka et al.[1] proposed a model to estimate the penetration depth of molten steel into a metallic tube as shown in Fig. 6. The penetration depth is determined by time until molten steel solidification, which is obtained by cooling rate according to the heat transfer calculation as expressed in Equation (1), and liquid flow speed, which is obtained by pressure drop in cylindrical tube and static pressure as expressed in Equation (2). They also validated the accuracy of the model by comparison of calculation and practical experiments carried out for tubes with diameters of 2 mm and 4 mm. The results are summarized in Fig. 7.

The formula for the solidification of molten steel into a tube:

$$t_s = r \cdot f(C_p \cdot \Delta T + L)/2h(T_s - T_w) \quad \cdots\cdots (1)$$

The formula for the intrusion depth of molten steel into a tube:

$$(2/3)(d/4f)\{(1+4fl/d)3/2-1\} = [2g(h_m - h_g - 2\sigma/\rho g r)] \cdot 1/2 \cdot t_s \quad \cdots\cdots (2)$$

Where,

t_s : time required to solidify (s)
r : radius of tube (cm)
ρ: density of molten steel (g/cc)
C_p : specific heat of molten steel (cal/(g・℃))
ΔT : difference between molten steel temperature and solidus temperature (℃)
L : specific latent heat (cal/g)
h : coefficient of heat transfer (cal/(cm^2·s·℃))
T_s : solidus temperature (℃)
T_w : temperature on surface inside tube (℃)
f : friction factor (-)
l : penetrating depth of steel (cm)
g : gravitational acceleration (cm/s^2)
h_m : static pressure of molten steel (cmFe)
h_g : remaining gas pressure inside tube (cmFe)
σ : surface tension of molten steel (dyn/cm)

Calculation parameters were given as follows:

C_p = 0.214 (cal/((g・℃))
$h(T_s - T_w)$ = 150
f = 0.02
L = 33 (cal/g)

h_m = 400 (cm)
σ = 1500 (dyn/cm)

As the tube diameter becomes smaller, the penetration depth decreases according to an increase in pressure drop. On the other hand, the little pressure drop is desirable from the viewpoint of gas provider.

Thus, the influence of tube diameter on pressure drop for gas purging was assessed by Equation (3). The results are shown in Fig. 8. Taking calculation results, cost, and productivity into consideration, tubes with a diameter of 3 mm were adopted for a porous plug with the PKG device.

$\Delta p = 4f_g \cdot (l/d) \cdot \rho \cdot u^2/2$ ……………………………… (3)

Fanning's equation

$Re = \rho ud/\mu = ud/\nu$ …………………………………… (4)
$f_g = 0.0791Re^{-0.25}$ ………… (5)　Blasius' equation Where,

Δp : Pressure drop (Pa)
f_g : Friction factor (-)
l : Tube length (mm)
d : Tube diameter (mm)
ρ : density of gas (kg/m^3)
u : Average flow velocity (m/s)
Re : Reynolds' number (-)
μ : viscosity of gas (kgf/cm^2)
ν : kinetic viscosity of gas (m^2/s)

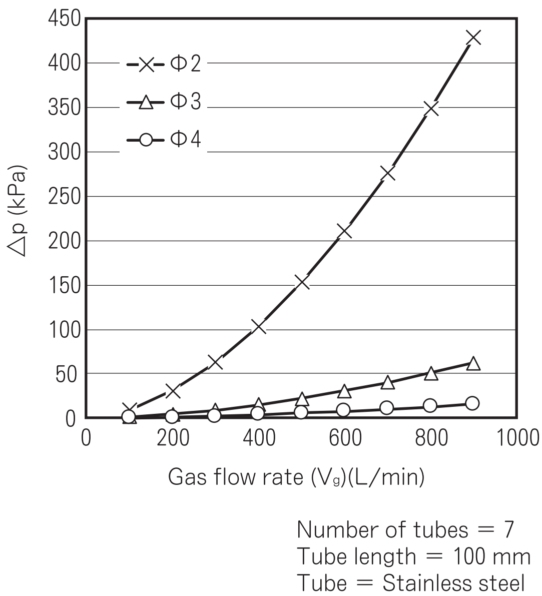


Fig. 8　Calculated values of pressure loss according to tube size.

Calculation parameters were given as follows :
v = 1.512 × 10^{-5} (m^2/s) kinetic viscosity of air (20℃)
ρ = 1.205 (kg/m^3)　density of air (20℃)
l = 100

Here, the total gas flow provided through seven tubes is assumed as Vg so that flow velocity u is expressed by the following Equation:

$u = V_g/(7 \cdot \pi (2/d)^2)$

5.　Performance of PKG-BLOCK

Schematic illustrations of PKG-BLOCK and W-PKG-BLOCK and typical properties of refractories for the blocks are shown in Fig. 9 and Table 1, respectively. PKG-BLOCK, which is basically composed of a porous plug and a seating well block was designed to obtain a target service life and be capable of blowing gas over the entire service life. W-PKG-BLOCK, in which two or more plugs are mounted, is also commercially available. Its service life can be extended by switching the gas purging position where local wear occurs.

A comparison of performance between PKG-BLOCK and conventional porous plugs is shown in Table 2. The representative features of PKG-BLOCK are stated below.

1. The biggest advantage of PKG-BLCOK is preventing molten steel leakage completely even when the plug is used beyond its service life thanks to the function of carefully arranged metallic tubes behind the porous medium.
2. PKG-BLOCK can be easily installed by lowering down to the ladle bottom with overhead traveling cranes on site because of the prefabricated assembly.
3. PKG BLOCK does not require any device for fixing the plug such as a Bayonet or plug replacement equipment. Additionally, redesign of the ladle bottom shell is not necessary. Hence, significant reduction of initial and running costs is expected.
4. PKG BLOCK does not require any special care during use, for example, checking the service life indicator of plug.

A cross-sectional photo of a PKG-BLOCK that was taken out of the ladle after 19 heats as scheduled is shown in Fig.10. The hot face of the block was worn smoothly in the both porous and non-porous areas. The gas flow was stable under a prescribed range of gas pressures in all heats.

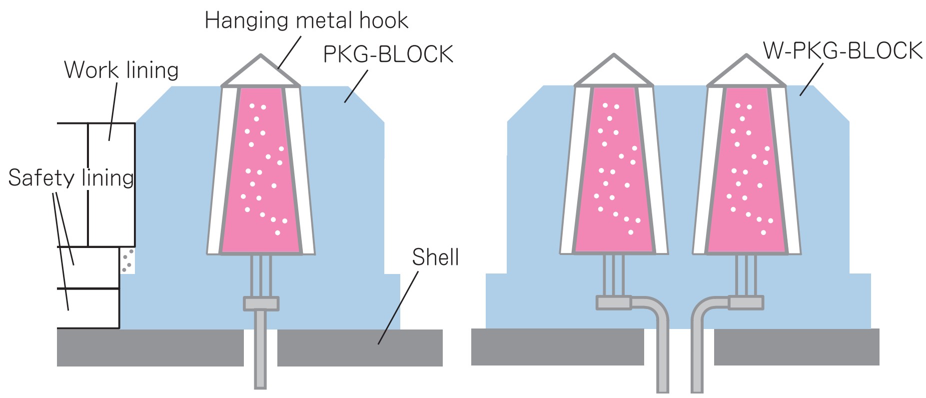


Fig. 9 Schematic illustration of porous plug assemblies “PKG-BLOCK” and “W-PKG-BLCOK”.

Table 1 Chemical and physical properties of refractories for PKG-BLOCK

Code	HSP203	CAM7-PW37	CAM7-C-AH-R(37)
Material	High Alumina	Alumina Magnesia	Alumina Magnesia
Application	Porous brick	Sleeve	Seating block
Chemical composition / %			
SiO_2	7		
Al_2O_3	86	91	90
Cr_2O_3	1.8		
MgO		7	7
ZrO_2	3		
Apparent porosity / %	20.9	18.5	18.5
Bulk density	2.86	3.02	3.02
Cold crushing strength / MPa	89	23	34

Table 2 Performance comparison between conventional porous plug and “PKG-BLOCK”

	Conventional porous plugs (External mounting-type)	"PKG-BLOCK"
Gas purging performance	◎	◎
Service life	△~○	○~◎
Safety level	△	◎
Cost performance of purging plugs, equipments and other external devices	△~○	○~◎
Maintenance workability in operation	△	◎

◎ Excellent
○ Good
△ Fair

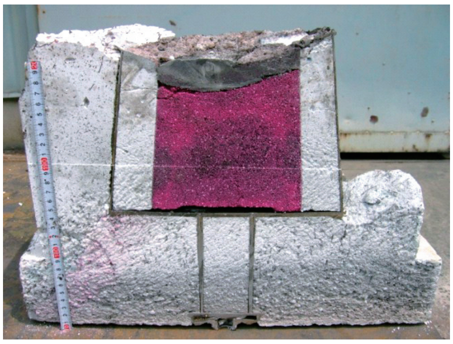


Fig. 10 Cross section of "PKG-BLOCK" after use (19heats, LF)

Supply records of porous plug PKG and PKG-BLOCK are shown in Table 3.

6. Summary

The prevention of molten steel leakage from porous plugs is of the highest priority because the plugs are directly installed on the steel shell of the ladle bottom. Several standard plug designs which are equipped with steel melt leakage preventive devices were introduced in this paper.

1. The structure of porous plug and ladle bottom shell should be designed in consideration of reducing the outflow of leaked steel in order to minimize the extent of break-through troubles.
2. Porous plug with the PKG device drastically reduces the risk level of molten steel leakage even when the number of heats exceeds the serviceable limits thanks to the fine metallic tubes equipped behind the porous core, which function as gas provider as well as penetrated steel solidifier.
3. 3 mm is the optimum diameter for tubes behind the porous core in consideration of gas purging, cooling ability of penetrated molten steel, and productivity.
4. The Porous plugs with PKG device are currently used at many steel mills with excellent performance.

Table 3 Supply records of porous plug "PKG" and "PKG-BLOCK"

User	Steel grade	Refining process	Ladle capacity / t	Service Life / hts	Plug height / mm	Size of small diameter tubes			Number of tubes
						ID / mm	OD / mm	L / mm	
A	Stainless	VOD/LT	90	30	380	3	5	97.3	7
B	Stainless	VOD/LF	60	23	380	3	5	125	7
C	Stainless	VOD/LF	80	32	473	3	5	80	7
D	Stainless	VOD	50	4-6	279	3	5	60	7
E	Carbon	LF	130	20-30	363	3	5	80	7
F	Carbon	LT	80	40-45	505	3	5	80	7
G	Carbon	LF	150	25	410	3	5	65	7
H	Special	LF	25	5	238	3	5	40	7

Reference

1) H. Yamanaka, T. Yoshida, F. Sudo, S. Yamada, T. Terada and M. Saegusa : Tetsu-to-hagané, **66** [11] S887 (1980).