REPORT

Introduction to The Technology of Gas Purging Plug Refractories for Steelmaking EAF

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Abstract

Metal bath stirring by inert gas blowing from the furnace bottom, so called bottom gas blowing, is one of the technologies introduced in the evolutionary process of EAF steelmaking. Various metallurgical benefits, such as reduction of energy consumption, shortening of refining time or improvement of steel yield, were confirmed by trial operations of bottom gas blowing at many EAF facilities. Due to accompanied problems, such as service life of gas purging plug refractory, overall cost of bottom gas blowing system or complexity in purging plug replacement, practical application of bottom gas blowing was limited in the initial stage. However, in association with improvement in the service life of the purging plug or optimizations in bottom gas blowing operation, bottom gas blowing has been commonly used, especially in the stainless or special steel making EAF in which the effects of the introduction of the bottom gas blowing system have been relatively large. It is prospected that, in association with progress of activity toward realization of carbon neutrality, further development or innovation in EAF bottom gas blowing technologies will be necessitated so as to respond to arising EAF steelmaking requirements.

1. *Introduction*

Rated as an efficient recycling process to exploit steel scrap resources, the electric arc furnace (hereinafter referred to as EAF) steelmaking process greatly contributes to the recycling society. In the evolutionary process of EAF steelmaking, a variety of technologies for productivity improvement or environment load reduction, such as furnace capacity enlargement, eccentric bottom tapping (EBT) system, direct current EAF or environmentally friendly EAF, have been introduced[1-3]. Metal bath agitation by inert gas blowing from furnace bottom (hereinafter referred to simply as bottom gas blowing), which was developed and introduced in late 1980s, is one of those innovative technologies. As a results of trial operations of bottom gas blowing at many EAF facilities, various kinds of metallurgical benefits, such as reduction of energy consumption[4,5], shortening of refining time[6] or improvement of steel yield[7,8], were affirmed. Because of accompanied problems, such as gas purging plug refractory service life, overall cost of the bottom gas blowing system and complexity in purging plug replacement, application of bottom gas blowing system was limited. However, in association with improvement in the service life of the purging plug and optimizations in bottom gas blowing operation, the bottom gas blowing system has been commonly and regularly used, especially at the EAF for stainless or special steel production, in which the effects of the introduction of the bottom gas blowing system have been relatively large[9].

While, in the activity plan toward realization of carbon neutrality in 2050 which has been declared by many steel industry entities, the maximum utilization of EAF steelmaking process, which is characterized

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by a small amount of CO_2 gas emission, is ranked as an important challenging issue. It is inferred that, because of difficulties in EAF steelmaking of high-grade electrical steel or ultimate high-strength steel, which are usually produced in the blast furnace-converter furnace steelmaking process at present[10, 11], many technical developments and innovations would be required. It is also inferred that, for a production shift from blast furnace-converter furnace steelmaking process to EAF steelmaking process to take place, further enlargement of furnace capacity would be required so as to secure productivity and cost competitiveness. It is prospected that, since unevenness in temperature and chemical compositions in metal bath tend to increase in an enlarged furnace capacity EAF, necessity for metal bath agitation by bottom gas blowing is increased as supplemental technology for furnace capacity enlargement.

When retroactively reviewing technical articles on bottom gas blowing at EAF, many of them were written in the period when bottom gas blowing system was developed and introduced for trial or practical operation, followed by reporting items of improvement activities for EAF operation. Hence, focusing on refractories used for bottom gas blowing system in EAF, precedent bottom gas blowing technologies in EAF are comprehensively reviewed in this article along refractory products and/or technologies which can be offered / provided by Shinagawa Refractories Co., Ltd. (hereinafter referred to as SRC)

2. Refractories for Bottom Gas Blowing System in EAF

Refractory configuration of EAF bottom gas blowing system, which consists of one set of gas purging plug and surrounding blocks (collectively called as bottom gas blowing tuyere, or simply, as tuyere) and outer supporting bricks, is schematically illustrated in Fig. 1. In the safety and working lining layers of the EAF furnace bottom, magnesia brick and stamping refractory mix composed of magnesia clinker or dolomite clinker are relined, respectively. When the working lining layer refractory is damaged, the damaged area is locally repaired with the same stamping mix or gunning mix so as to maintain a level of furnace bottom or metal bath surface in EAF operation. Recently, to suppress damages on the bottom refractories, the EAF bottom is wholly or partially relined with MgO-C bricks characterized by superior corrosion and thermal shock resistance.

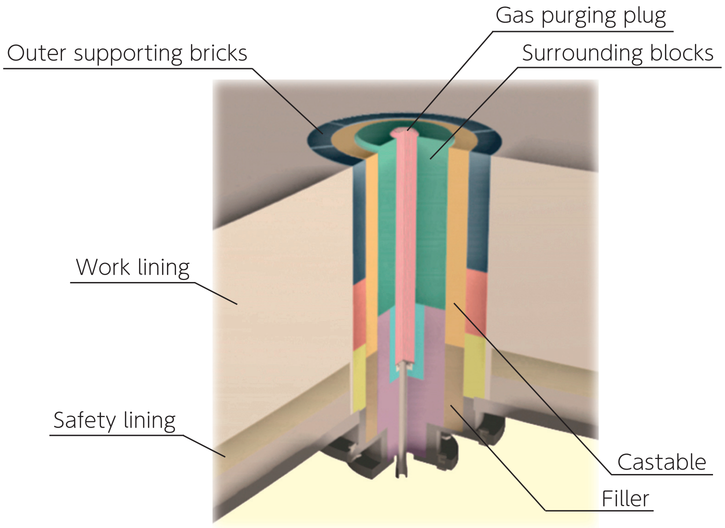


Fig. 1 Schematic drawing of refractories for bottom gas blowing installed at the bottom of an EAF.

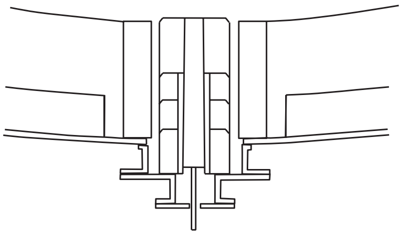
Table 1 Chemical composition and physical properties of refractories applied for EAF bottom blowing system

Quality	MgO-C	Alumina	MgO-C	Alumina
Code	SRT-3AS1	CAM7 (KGC)	MGT-5CH1	CH18-PW931
Application	Gas purging plug	Gas purging plug	Surrounding block Outer supporting bricks	Outer supporting bricks
Apparent porosity / %	3.6	19.4	3.8	16
Bulk density / -	2.97	3.02	2.92	3.1
Cold crushing strength / MPa	46	23	30	34
Chemical composition / %				
MgO	79	6.5	75	-
Al_2O_3	-	90	-	90
F.C	16	-	20	-
Remarks		Precast Carbon-free		Precast

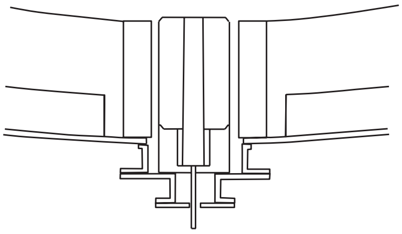
The bottom gas blowing tuyere is set at the bottom center and/or at a location which corresponds to the upper electrode position. The outer supporting block is situated around the bottom gas blowing tuyere which consists of a gas purging plug and surrounding bricks, and the gap between tuyere bricks and outer supporting block is filled up with monolithic refractory filling material.

The major specifications of refractories applied to the bottom gas blowing system at the EAF are shown in Table 1. MgO-C brick is usually applied for the gas purging plug, surrounding block and outer supporting bricks. As described later, precast block made of alumina castable refractory is occasionally applied for the gas purging plug. In association with lining method of monolithic refractory filling material, such as stamping, casting or press-fitting, monolithic refractory filling material composed of magnesia can be provided in various types of refractory products.

Two types of bottom gas blowing tuyere assemblies are shown in Fig. 2. One is a separatable of assembly of which the refractory components are set on site or assembled at the manufacturer's plant in advance, and another is mono block type assembly with a small number of divided refractory components. In separatable assembly system, according to damage level, each refractory component can be individually exchanged. When mono block type bottom gas blowing tuyere assembly needs to be replaced because of given damages, all of the refractory components are automatically renewed with an advantage that the replacing work can be carried out without complications in relatively short time. In recent years, mono block type assembly has become dominant.



a) Separatable



b) Mono block

Fig. 2 Two types of bottom blowing tuyere assemblies installed at the bottom of an EAF.

Table 2 Comparison of metal bath stirring refractory products

Type of plug	Multi-hole		Porous
Use for	EAF	BOF	Ladle (LF,VOD etc.)
Gas pass through	Small diameter tubes	Small diameter tubes	Pores in refractories
Inner diameter of tubes / mm	ϕ1 - 2	ϕ1 - 2	100–300 μm (Average pore size)
Number of tubes	3 - 20	50 - 200	-
Refractory	MgO–C	MgO–C	High alumina

3. *Design Criteria of Multi Hole Plug (MHP) for EAF*

The gas purging plug applied to the EAF is a refractory brick in which stainless steel tubes are embedded as passages for bottom blowing gas. It is so called as multi hole plug (MHP). The characteristics of MHP used at EAF are summarized in Table 2 compared with the MHP used at converter furnace and porous plug applied for metal bath agitation in the LF or VOD process. Because of the large difference in required bottom blowing gas flow rate between converter furnace and EAF operation, the number of stainless steel tubes embedded in the MHP greatly differs with each type.

The MHP is exposed to a certain static steel pressure depending on the molten steel metal bath depth. When the back pressure of bottom blowing gas lowers, molten steel penetrates into the stainless steel tubes and solidifies in the stainless steel tube at a certain depth from top end[12]. The pressure drop of the bottom blowing gas, which is induced by friction between flowing gas and inner stainless steel tube surface, is influenced by the inner diameter of stainless steel tube[13]. Combining these two factors and other issues, such as cost and compatibility in manufacturing process, a 1–2 mm inner diameter stainless steel tube was experientially adopted. Several design examples of MHP applied for EAF bottom gas blowing are shown in Table 3.

Table 3 Design examples of gas purging plugs applied at EAF

Steel grade	EAF		Purging plug
	Electric current	Heat size / t	Inner diameter of tubes / mm
Carbon	AC	100–150	ϕ1.5
Special	AC	100–150	ϕ1.5
Special	AC	100–150	ϕ1.5
Special	AC	50–100	ϕ1.5
Special	AC	<50	ϕ1.0
Stainless	AC	>150	ϕ1.5
Stainless	AC	100–150	ϕ1.5
Stainless	AC	50–100	ϕ1.5
Stainless	AC	50–100	ϕ1.0
Stainless	AC	50–100	ϕ1.5
Stainless	AC	50–100	ϕ1.5
Stainless	AC	50–100	ϕ1.5
Stainless	AC	50–100	ϕ1.5

When bottom gas blowing is suspended during practical EAF operation, molten steel easily flows into the stainless steel tubes, resulting in MHP clogging. The bottom blowing gas flow pattern applied for stainless steel refining in EAF with 42 ton furnace capacity[8] is shown in Fig. 3. The flow rate of bottom blowing gas is varied according to EAF operation progress. That is, Ar or N_2 gas is blown at 100 L/min and 30–50 L/min of flow rate in the melting period

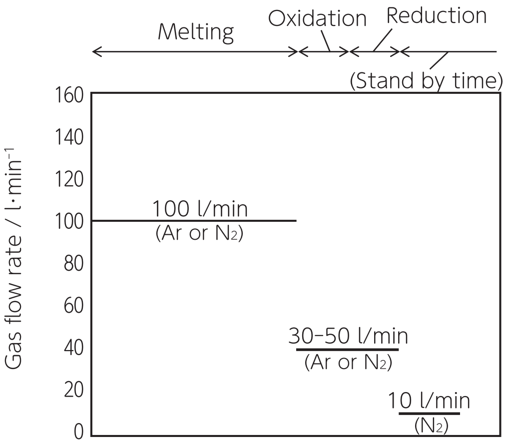


Fig. 3 Bottom blowing gas flow pattern applied for stainless steel in 42ton EAF [8].

and oxidation/reduction period, respectively. During stand-by time, N_2 gas is constantly supplied to the MHP at 10 L/min of flow rate so as to prevent clogging of the gas blowing nozzle.

4. Effects of Bottom Gas Blowing in EAF

The molten steel metal bath depth in an ellipse shaped EAF furnace body is relatively shallow and flat. In comparison with direct current EAF (DC EAF) in which, since molten steel is stirred by electromagnetic force induced by direct electrical current flowing from the upper electrode to bottom electrode, metal bath temperature distribution is uniformized, the metal bath temperature distribution in an alternate current EAF (AC EAF) is quite uneven, occasionally accompanied by unmelted steel scraps or ferro alloy. To suppress uneven distribution of temperature and/or steel composition in metal bath, metal bath agitation by bottom gas blowing is applied. Among many reports on the effects of bottom gas blowing, which have been evaluated by fluid dynamics calculation [14], water model experiment [15,16], or demonstration experiment in small capacity EAF, several reports are reviewed as follows.

Nagao et al.[15] investigated the relation between inert gas flow rate blown from MHP, in which 1, 3 or 4 stainless steel tubes were embedded, and homogenization time by tracing temperature distribution in 70℃ hot water using a simplified water model experiment apparatus. The water temperature was measured by thermocouple at three different locations to determine how long it takes for the water temperature to homogenize in a water model experiment. The results of the water model experiment are shown in Fig. 4 along with stainless steel tube arrangements in the MHP gas purging plug. The effects of bottom gas blowing are summarized as follows.

(1) In accordance with the increase of bottom blowing gas flow rate, homogenization time is shortened.
(2) In association with the increase of the number of embedded stainless steel tubes in the MHP plug, homogenization time is shortened.
(3) Sufficient homogenization time is achieved with MHP in which 3 or more stainless steel tubes are embedded.

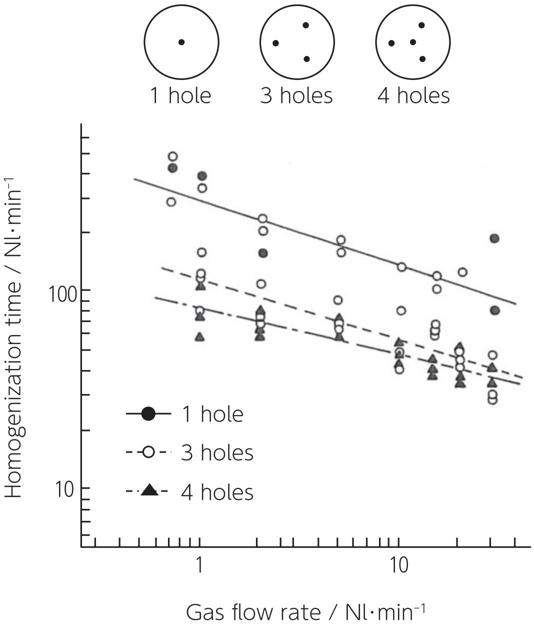


Fig. 4 Relation between gas flow rate and homogenization time and stainless tube arrangement in gas purging plug [15].

Using 1/5 scale EAF water model, Tate et al.[16] evaluated the effect of agitation by bottom gas blowing by analyzing videotaped movements of plastic beads dispersed in water model experiment

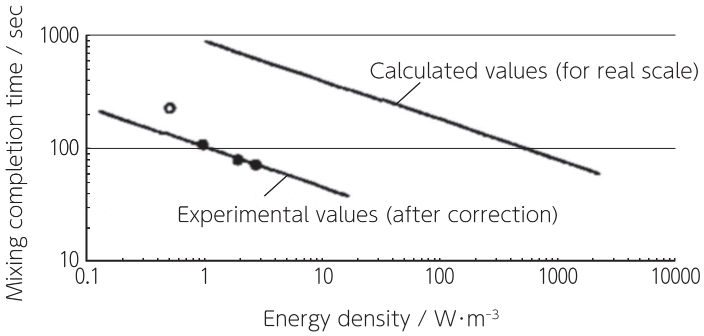


Fig. 5 Relationship between energy density and mixing completion time [16].

as well as by tracing changes in concentration of ink dropped in water model liquid with the aid of absorptiometer measurement. The relation between agitation energy density and mixing completion time, was obtained by organizing experiment data using a correction method followed by conversion to relationship to EAF with original dimensions. The results are shown in Fig. 5. Based on water model experiment results, the bottom gas blowing test was conducted in a practical EAF with 100-300 NL/min of gas flow rate per gas purging plug and 100-150 seconds of mixing completion time. A consistent value was obtained with water model calculation result.

Nakayama et al.[17] evaluated the metal bath stirring effect by bottom gas blowing in stainless steel making AC EAF with 20 tons of furnace capacity. The elapsed time for Cu composition to reach a saturated value was measured as homogenization time by tracing the composition of Cu which was intentionally added to molten steel metal bath during operation. The change in Cu composition according to metal bath mixing time is shown in Fig. 6. When N_2 or Ar gas was blown from furnace bottom with 100 NL/min of flow rate, the Cu composition in metal bath was homogenized within 220 seconds.

SRC developed EF-KGC, which is a bottom gas blowing system for the EAF based on refractory products applied for bottom gas blowing system in converter furnace and their peripheral technologies in 1980's when introduction of bottom gas blowing system to EAF started. The operational benefits of using EF-KGC at various EAF plants were investigated. In trial EAF operation using EF-KGC, the appropriate bottom blowing gas flow rate for steel grades and/or furnace capacity was determined by putting investigating the negative aspects, such as metal bath surface fluctuation or violent blow-out of bottom blowing gas, and effects of bottom gas blowing on the four operational issues, namely, (1) reduction of electric power consumption, (2) promotion of steel scrap melting, (3) improvement of yield ratio of Si and Mn (and Cr in stainless steel) and (4) promotion of desulfurization. The results are summarized in Table 4.

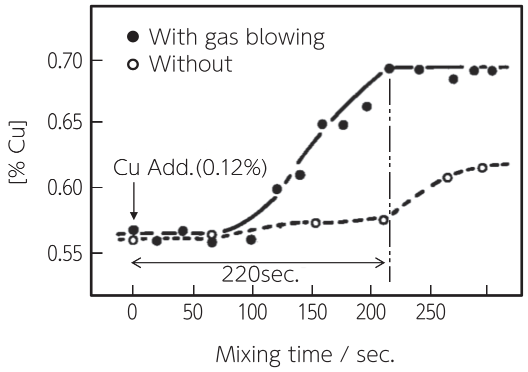


Fig. 6 Change of Cu composition by metal bath mixing time [17].

Based on investigation results, the relation between the furnace capacity and bottom blowing gas flow rate appropriated for each steel grade is shown as per Fig. 7. Regardless of furnace capacity, 30-70

Table 4 Trial operation with “EF-KGC” [15)]

User	Steel grade	Heat size / ton	Gas flow rate / Nl·min^{-1}	Gas	Power consumption reduction	Prevention of scrap melt residue	Yield ratio			De-S
							[Si]	[Mn]	[Cr]	
1	Carbon steel	<50	60	N_2	○	◎	○	○		○
2	Carbon steel	50-100	70	N_2	○	◎	○	○		○
3	Carbon steel	50-100	30-50	N_2	○	◎	○	○		○
4	Carbon steel	50-100	70	N_2	△	◎	△	△		△
5	Carbon steel	50-100	40-70	N_2	○	◎	○	○		○
6	Carbon steel	<50	30-60	N_2	○	◎	○	○		○
7	Carbon steel	50-100	40-60	N_2	○	◎	○	○		○
8	Carbon steel	50-100	40-60	N_2	○	◎	○	○		○
9	Carbon steel	50-100	40-60	N_2	○	◎	△	△		△
10	Carbon steel	50-100	40-60	N_2	○	◎	○	○		○
11	Carbon steel	50-100	40-60	N_2	○	◎	○	○		○
12	Special steel	<50	30-50	Ar	○	◎	○	○		○
13	Special steel	50-100	40-70	Ar	◎	◎	○	○		○
14	Special steel	<50	30-40	Ar	◎	◎	◎			○
15	Special steel	<50	30-70	Ar	◎	◎	○	○		○
16	Special steel	>150	40-70	N_2/Ar	○	◎	○	○		○
17	Special steel	50-100	30-50	Ar	◎	◎	○	○		○
18	Special steel	50-100	25-50	Ar	◎	◎	○	○		○
19	Special steel	<50	30	Ar	○	◎	○	○		○
20	Special steel	<50	30	N_2	○	◎	○	○		○
21	Stainless steel	<50	80-100	N_2	○	◎	○	○	◎	
22	Stainless steel	<50	90-150	N_2	○	◎				○
23	Stainless steel	50-100	100-150	N_2	○	◎			○	
24	Stainless steel	<50	50	N_2	○	◎	◎	○	◎	△
25	Stainless steel	100-150	100-150	N_2/Ar	○	◎				○
26	Stainless steel	<50	50	N_2	○	◎	◎	○	◎	△
27	Stainless steel	<50	30	N_2	○	◎			○	

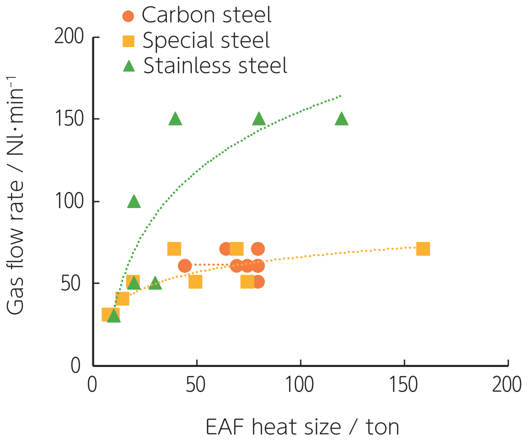
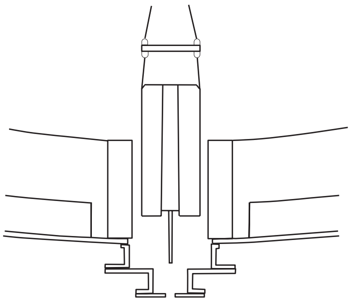


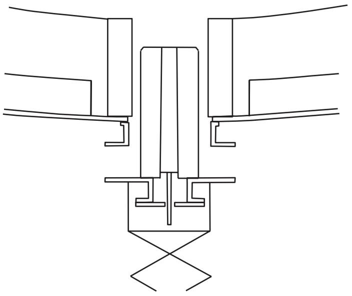
Fig. 7 Relation between furnace capacity and applied bottom gas flow rate.

L/min of bottom blowing gas flow rate is applied at EAFs, in which plain carbon steel or special steel is produced. In the stainless steel making EAF, the bottom blowing gas flow rate begins to increase at 20-30 tons of furnace capacity and 150 NL/min of the bottom blowing gas flow rate is applied at EAF with over 40 tons of furnace capacity. It is inferred that, since the yield ratio of Cr in stainless steel is greatly influenced by reduction operation, relatively high bottom blowing gas flow rate is required for intensive metal bath agitation in reduction operation.

Due to structural factors in EAF facility as well as relatively shallow metal bath depth, bottom gas blowing at EAF does not require such a high bottom blowing gas flow rate, and of bottom blowing gas flow rate is usually applied at present. It is reported, however, that the metal bath stirring effect achieved by bottom gas blowing in the EAF is equivalent to that in the VOD process[17]. It is noted that the commonly applied bottom blowing gas flow rate of 50–150 NL/min conformed to the above mentioned results in trial operation with EF-KGC.



a) Inward replacement



b) Outward replacement

Fig. 8 Two methods for replacing bottom gas blowing tuyere assembly.

5. Replacement of Bottom Gas Blowing Tuyere Assembly

Fig. 8 shows two methods for replacing the bottom gas blowing tuyere assembly, namely, inward replacement and outward replacement. In inward replacement, a new bottom gas blowing tuyere assembly supported by overhead crane is replaced from inside of the furnace. In outward replacement, a new bottom gas blowing tuyere assembly is inserted into the furnace from the furnace bottom side by lifter and fixed by bolting its flange to SPC. In both replacement methods, SRC can provide bottom gas blowing tuyere assembly which has been assembled at the manufacturer's plant in advance so as to enable simplified replacing work on site.

An example of outward replacement of the bottom gas blowing tuyere assembly is shown in Fig. 9. Replacement of the bottom gas blowing tuyere assembly is carried out with the following procedures.

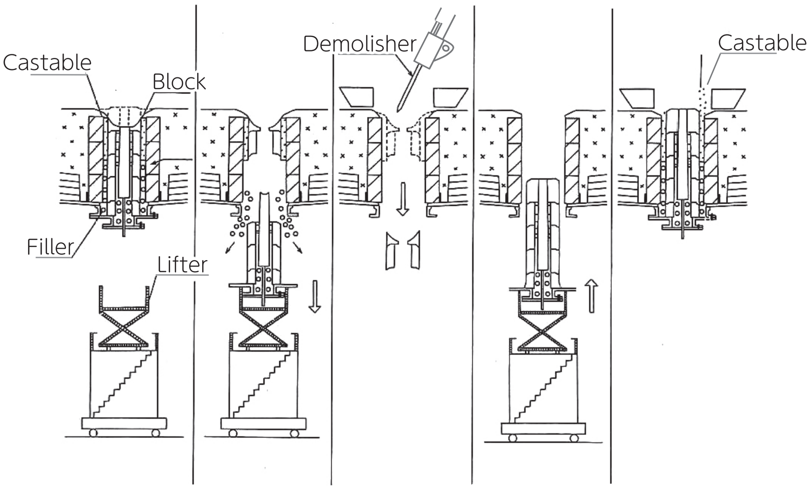
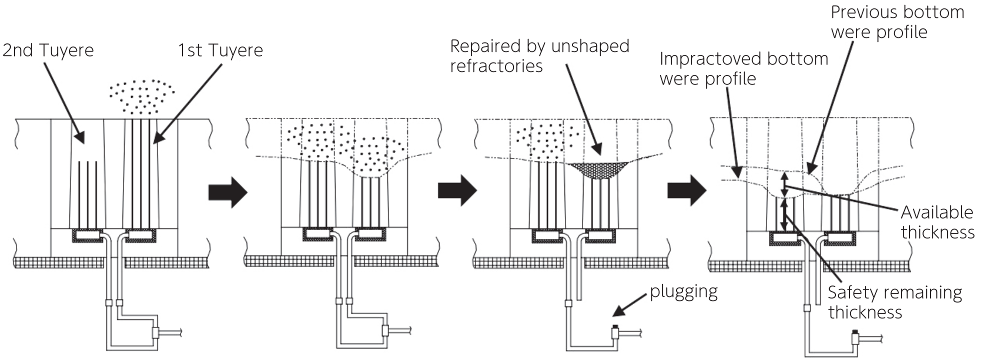


Fig. 9 An example of outward replacement of gas blowing tuyere assembly[15].



① Initial blowing ② Aeration from 2nd tuyere ③ Switchining gas line ④ Enf of campaign

Fig. 10 Schematic diagram of the use of combination tuyere[18].

(1) Setting of lifter and releasing fixed flange of used-up bottom gas blowing tuyere assembly
(2) Removal of old bottom gas blowing tuyere assembly from EAF furnace
(3) Demolishment of remaining tuyere block debris by breaker and their removal
(4) Insertion of new bottom gas blowing tuyere assembly and fixing its flange
(5) Filling gap between newly installed tuyere block and outer supporting block with filling material with low sintering strength and castable refractory

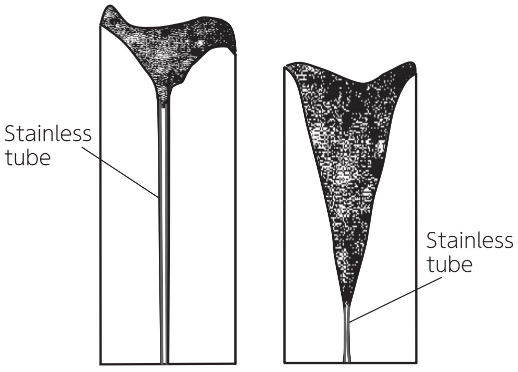
6. Unique Gas Purging Plug Provided by SRC

6. 1 Combination tuyere (Switchable tuyere)

Due to thermal and mechanical influences of bottom blown gas, refractory gas purging plug is damaged more severely than those relined in other parts of the EAF furnace bottom. In cases where, due to some factors in the EAF operation plan, replacement of refractory gas purging plug cannot be conducted, a combination tuyere[18] is applicable. In the combination tuyere, two gas purging plugs are set in large sized tuyere block along with a switchable blowing gas supply pipeline. A schematic diagram of switching over the gas purging plug is shown in Fig. 10. EAF operation starts with the 1st gas purging plug. When the 1st gas purging plug is worn to a certain extent, top end of the 2nd gas purging plug emerges. By finishing the gas blowing operation of the 1st gas purging plug, of which the upper surface is mended with hot repair refractory material, the gas supply line is switched over to the 2nd gas purging plug for further gas blowing operation. When the refractory wear reaches remaining safety limit thickness, the combination tuyere is replaced. The detail specifications of the combination tuyere are designed taking into account the refractory wear rate, target service life and timing for switch-over of gas purging plug.

6. 2 MHP composed of carbonless castable refractory

In addition to refractory damage by thermal spalling induced by the cooling/heating effect of



Normal wear Abnormal wear

Fig. 11 Schematic illustration of bottom gas blowing tuyere severely worn by selective damage onto embedded stainless steel tube.

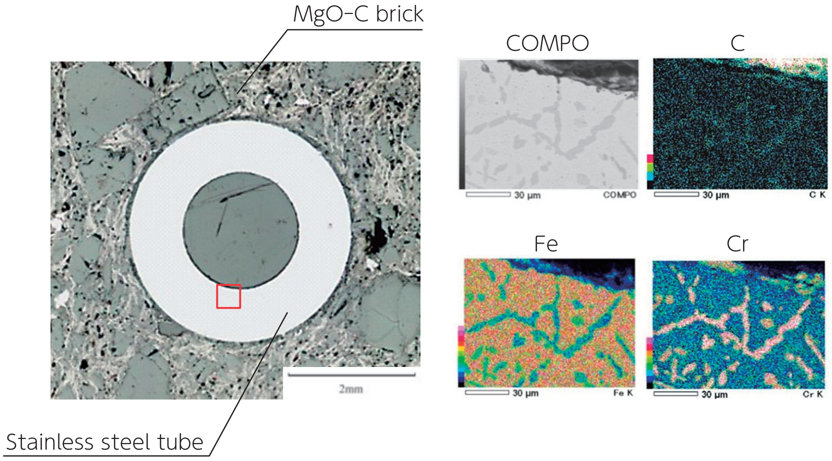


Fig. 12 Microphotograph and EPMA images of sensitized structure of stainless steel tube in MgO-C brick after heating at 1200℃.

gas blowing and/or mechanical damage by impact of charged steel scrap, the service life of the MHP is occasionally shortened by selective damage of embedded stainless steel tubes. Fig. 11 is a schematical illustration of a gas purging plug (In this case an example of a single hole plug is shown.) which is severely worn by selective damage onto embedded stainless steel tubes. Factors for selective damage of embedded stainless steel tube include (1) melting by molten steel[19), (2) embrittlement induced by carburizing of C contained in MgO-C refractory and (3) sensitization (localized deterioration caused by, as shown in EPMA images in Fig. 12, deficiency of Cr component at stainless steel grain boundary) induced by inappropriate thermal history. To prevent such selective damage, surface treatment on stainless steel tube or insertion of stainless steel tubes into protective tubes made of carbonless material is applied. When stainless steel tubes are embedded instead MgO-C refractory, carbonless alumina castable refractory represented by CAM7 (KGC) in Table 1, castable refractory body functions, similarly to above mentioned protection tube, to prevent selective damage. The gas purging plugs composed of carbonless castable refractories have advantages in terms of production cost and lead time compared to MgO-C gas purging plugs manufactured by CIP or uniaxial pressing and further work will be undertaken to optimize and improve the refractory and plug body structure.

7. Conclusion

Refractory products applied to bottom gas blowing on the EAF were reviewed in this article, along with metallurgical benefits observed in trial EAF operation in the early stage of bottom gas blowing technologies and practical usage of bottom gas blowing refractories. In association with developments in refractory and/or EAF steelmaking operation, EAF bottom gas blowing technologies established on the basis of trial EAF operation in the early stage has been changed to conform to the present. It is prospected that, in association with progress of activity toward realization of carbon neutrality, requirements for refractory technologies in EAF steelmaking operation will be altered and further development or innovation in EAF bottom gas blowing technologies will be necessitated.

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