

SHINAGAWA TECHNICAL REPORT

電気炉製鋼における底吹き耐火物技術

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

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要 旨

炉底に設置した底吹きプラグ(マルチホールプラグ)から不活性ガス吹き込みにより鋼浴を攪拌する、いわゆる底吹きガス攪拌は、電気炉製鋼法の発展過程において導入された技術の1つに挙げられる。その導入期である1980年代後半には、既に転炉において一般化していた技術でもあり、多くの電気炉設備において試験的運用が開始された。その結果、エネルギー原単位の削減、精錬時間の短縮、メタル歩留の改善などの操業効果が確認された。一方、底吹きプラグの耐用回数、プラグ交換の困難さ、底吹き用耐火物と周辺システム含めたトータルコストに課題があり、その適用は限定的であった。その後、プラグ耐火物の改善、操業方法の最適化、施工技術の確立により、相対的に導入効果の大きかったステンレス鋼や特殊鋼などの鋼種を溶製する電気炉において実用化された。カーボンニュートラル実現に向け、既に動き始めている様々な取り組みの中で、電気炉製鋼における新たな要求に対して、更に底吹きプラグの開発・改良が必要になることが予想される。

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. 緒言

電気炉製鋼法は、鉄資源を有効活用するためのリサイクルプロセスとして高く評価されており、循環型社会の構築に大きく貢献している。その発展過程においては、炉容大

1. Introduction

Rated as an efficient recycling process to exploit steel scrap resources, the electric arc furnace (hereinafter referred to as EAF) steelmaking process

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型化，偏芯炉底出鋼方式(EBT)，直流式電気炉，環境調和型電気炉といった生産性向上や環境負荷軽減のための様々な技術が導入された¹⁻³⁾。1980年代後半に導入された底吹きガス攪拌技術もその1つであった。各社での多くの試験的運用の結果，エネルギー原単位の削減^{4,5)}，精錬時間の短縮⁶⁾，メタル歩留の改善^{7,8)}などの冶金的，経済的效果が確認されたが，底吹きプラグの耐用，交換性，システム含めたトータルコストなどに課題があったため，その適用は限定的であった。その後，底吹きプラグの耐用性や施工方法の改善，操業の最適化などが進み，ステンレス鋼や特殊鋼など相対的に導入効果の大きい鋼種を溶製する電気炉を中心に実用化された⁹⁾。

近年，鉄鋼各社より公表された2050年カーボンニュートラル実現に向けた取り組みの中で，CO₂排出量の少ない製鉄プロセスである電気炉の最大活用は，重要課題となっている。高炉-転炉法で製造される電磁鋼板やハイテン材などの製造が電炉法では困難であり^{10,11)}，その実現には多くの技術課題も含まれる。更に高炉法を電炉法に置き換える場合，高い生産性とコスト競争力を維持するため，既存の電気炉の更なる大型化も必要となる。大型電気炉では，炉内溶鋼の温度と成分の均一化を困難にし，その補完技術としての底吹き攪拌の重要性が高まると予想される。遡ると，電気炉における底吹き攪拌に関する技術報告はその普及期に多いものの，その後は操業改善の取り組みの一例として扱った報告に限られる。そこで本報告では，電気炉底吹き攪拌に関する耐火物を中心としたこれまでの技術について包括的に述べ，当社耐火物とその使用技術についても紹介する。

2. 電気炉底吹きプラグと周辺耐火物の構造

底吹きガス攪拌に必要な耐火物は，底吹きプラグ本体とそれを取り囲む羽口れんが(これらを1組として底吹き羽口，または単に羽口と総称する場合もある)，更にその周囲のサポートれんがから構成される。Fig.1に，これら一式が電気炉炉床に設置された概略図を示す。炉床パーマ材にはマグネシアれんが，ワーク材にはマグネシアクリンカーやドロマイトクリンカーを主成分とするスタンプ材が打設され，損傷に応じて，同一の炉床材や吹き付け材等で補修し，炉床レベルを維持しながら操業する方法が一般的である。また炉床の損傷改善のため，部分的もしくは全面的に耐食性と耐熱スポーリング性に優れたMgO-Cれんがをライニングすることも最近では少なくない。底吹き羽口は，炉床の中央や電極に対応する位置に埋設，施工される。更に羽口の周囲にはサポートれんが，羽口とサポートれんが

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 introduced¹⁻³⁾. 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 time⁶⁾ 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 large⁹⁾.

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 by a small amount of CO₂ 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

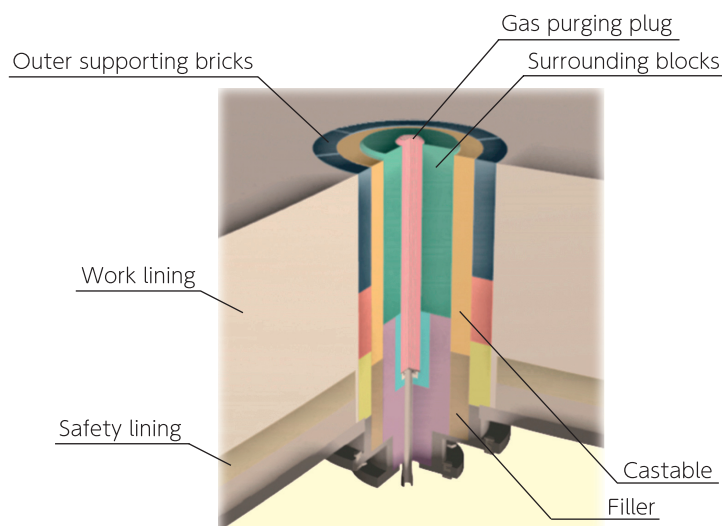


Fig. 1 Schematic drawing of refractories for bottom gas blowing installed at the bottom of an EAF.

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

Quality Code	MgO-C SRT-3AS1	Alumina CAM7 (KGC)	MgO-C MGT-5CH1	Alumina 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 ₂ O ₃	-	90	-	90
F.C	16	-	20	-
Remarks		Precast Carbon-free		Precast

の隙間には不定形充填材が施工される。

当社製の底吹き耐火物の品質をTable 1に示す。底吹きプラグと羽口、サポートレンガはMgO-Cレンガであり、プラグ耐火物として後述するアルミナ質プレキャストブロックも採用される場合もある。不定形材はマグネシア質であり、スタンプ施工が最も一般的であるが、流し込み施工、圧入施工が可能な形態でも提供できる。

Fig.2に、2つのタイプの底吹き羽口を示す。1つは古くから使用されている、各レンガパーツをアセンブル可能な分割タイプであり、もう1つは分割数を少なくしたモノブロックタイプである。分割タイプは、損傷したノズルと、羽口レンガのうち損傷部位だけを交換できるメリットもあ

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)

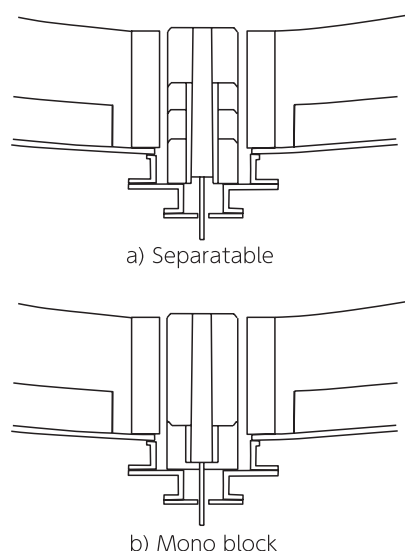


Fig. 2 Two types of bottom blowing tuyere assemblies installed at the bottom of an EAF.

る。モノブロックタイプは 交換が必要と判断された場合、すべての部分の交換となるが、交換作業時間の短縮の観点から煩雑さはなく容易に交換できることにメリットがある。近年では後者のモノブロックタイプの使用比率が高い。

3. 電気炉底吹きノズル細管の設計

電気炉用底吹きプラグは、耐火物中に埋設された金属細管を通じてガスを吹き込む、いわゆるマルチホールプラグ (MHP) であり、転炉用、取鍋用 (ポラスプラグ) との比較を Table 2 に示す。転炉用と電気炉用では、目標とするガス流量が異なることから、細管本数に大きな違いがある。

底吹きプラグの上部には湯面高さに応じて溶鋼静圧が生

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. 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

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	$\phi 1-2$	$\phi 1-2$	100-300 μm (Average pore size)
Number of tubes	3-20	50-200	-
Refractory	MgO-C	MgO-C	High alumina

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

じ、底吹きガスの背圧が低下した場合、金属細管内へ溶鋼が浸入し、一定深さで凝固する¹²⁾。一方、金属細管内をガスが通過する際の摩擦力から生じる圧力損失も細管径の影響を受ける¹³⁾。これらに加えて、製造上のコスト・汎用性を考慮し、経験的に細管直径は1~2mmで設計される。現在電気炉用として流通している底吹きプラグの設計例のいくつかをTable 3に示す。

実操業時においてガス吹き込みを完全に停止した場合は、溶鋼の細管への侵入を容易に許し、ノズル詰まりを引き起こす。上村ら⁸⁾により報告されたステンレス鋼を溶製する42t電気炉における実操業時のガス吹きパターンをFig.3に示す。底吹きガス流量は、電気炉操業の時間により変化する。すなわち、溶解期には100l/min、酸化・還元期には30~50l/minのArもしくはN₂ガスが吹き込まれ、更に休止時には10l/minのN₂ガスが吹き込むことによって次のチャージまで待機する。休止時のガス吹き込みは、ノズル詰まり防止を図るために常時実施される。

4. 電気炉における底吹き攪拌の効果

電気炉は、浅鋼浴、上広形状をした精錬容器である。電磁力による溶鋼攪拌が得られる直流式電気炉と異なり、交流式電気炉においては鋼浴内の偏熱傾向があり、大型スクラップや合金の溶け残りが発生しやすい。これまで底吹き

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 separable 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 separable 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.

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 end¹²⁾. 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 tube¹³⁾. 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.

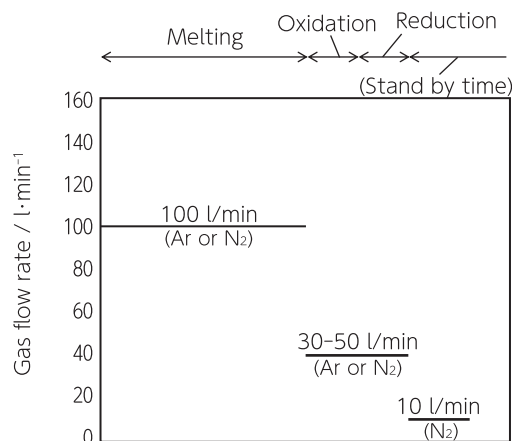


Fig. 3 Bottom blowing gas flow pattern applied for stainless steel in 42ton EAF⁸⁾.

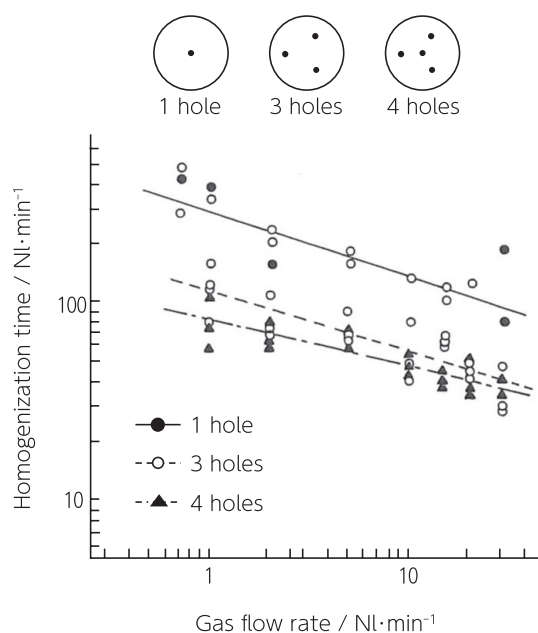


Fig. 4 Relation between gas flow rate and homogenization time and stainless tube arrangement in gas purging plug¹⁵⁾.

攪拌の有効性は、流体力学的計算¹⁴⁾、水モデル実験^{15,16)}、小型電気炉における実証実験などによって評価したいくつかの報告があり、その中から抜粋して紹介する。

長尾ら¹⁵⁾は、簡易的な水モデル実験装置によって、底吹きプラグに埋設するステンレス細管数を1, 3, 4本と変化させたときのガス吹き込み量と均一化時間の関係を70℃の温水をトレーサーとし調査した。均一化時間は浴槽内の3か所の水温が一定になったことを熱電対で確認することにより求めた。実験に使用したプラグの細管配列と実験結

Several design examples of MHP applied for EAF bottom gas blowing are shown in Table 3.

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 capacity⁸⁾ is shown in Fig. 3. The flow rate of bottom blowing gas is varied according to EAF operation progress. That is, Ar or N₂ gas is blown at 100 L/min and 30-50 L/min of flow rate in the melting period and oxidation/reduction period, respectively. During stand-by time, N₂ 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 calculation¹⁴⁾, 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.

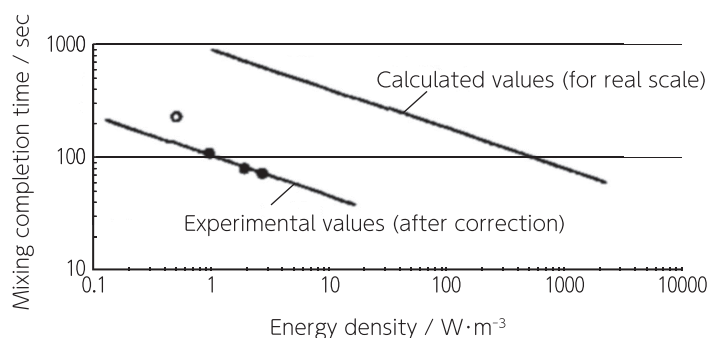


Fig. 5 Relationship between energy density and mixing completion time¹⁶⁾.

果をFig.4に示す。この実験により、以下の結果が得られている。

- ① ガス吹き込み量と増加とともに均一化時間は減少した。
- ② 細管本数の増加により、均一化時間が減少した。
- ③ 細管本数が3本以上で十分な均一化時間が得られた。

楯らは¹⁶⁾、実際の電気炉の1/5スケール水モデル装置を用いて、液中に分散させたプラスチックビーズの動きのビデオ観察とインク濃度の変化を吸光高度計により測定することにより、攪拌効果を評価した。測定結果を補正式によって整理し、攪拌動力密度と均一混合時間の関係を求め、実スケールでの式に変換した。その結果をFig.5に示す。この実験結果を元に、実機電気炉においてプラグあたり100～300NL/minのガスを吹き込む試験を行ったところ、100～150秒で均一化時間となり、計算結果とのおおむね一致したことを確認した。

中山ら¹⁷⁾は、ステンレス鋼を溶解する20tの交流式電気炉において、底吹き攪拌効果を、Cuをトレーサーとする溶鋼成分均一化時間で評価した。Fig.6に攪拌時間とCu濃度

- (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.

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 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 100-300NL/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

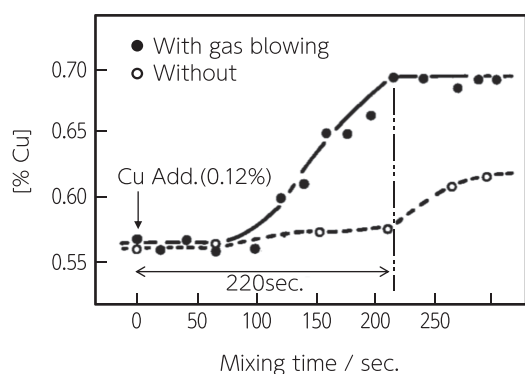


Fig. 6 Change of Cu composition by metal bath mixing time¹⁷⁾.

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	○	◎			○	

の関係を示す。N₂またはArガスを100NL/minで吹き込みを行った場合、220秒で均一化時間に達した。

当社は、電気炉における底吹き攪拌の導入期である1980年代に転炉底吹き羽口の耐火物とその周辺技術を元にした電気炉底吹きシステム“EF-KGC”を開発し、各ユーザーの製造現場において底吹き攪拌の操業効果の評価を行った。その結果をTable 4に示す。多くのユーザーにおけるトライアルの結果、鋼種、炉容量に対するガス操業流量を、溶鋼湯面の変動やガスの吹上げの有無を考慮し決定した。更に以下に示す操業効果をユーザー毎に確認し、評価した。

to metal bath mixing time is shown in Fig.6. When N₂ 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

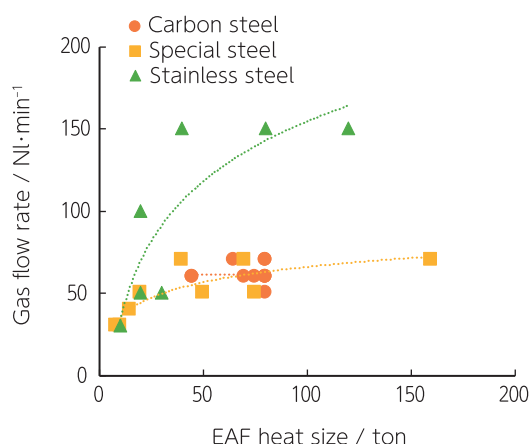


Fig. 7 Relation between furnace capacity and applied bottom gas flow rate.

- ① 電力消費量の低下
- ② スクラップ溶解促進
- ③ Si, Mn歩留の向上（ステンレス鋼のみ、Cr歩留）
- ④ 脱硫促進

操業ガス流量と電気炉容量の関係を鋼種毎に整理した結果をFig.7に示す。ガス流量は、普通鋼および特殊鋼電気炉においては炉容量に関わらず、操業ガス流量が30～70NL/minであった。一方、ステンレス鋼の場合、炉容量が20～30tの領域で操業ガス流量が上昇し、40t以上では150NL/minのガス吹き込みが必要となった。このことはステンレス鋼が高合金鋼であり、Cr歩留が操業により差が生じやすいことから、攪拌のためのより大きなガス流量が必要となったためと推定される。

電気炉での底吹きガス攪拌は、先に述べたように構造的な要因や湯面の高さからあまり多くのガス流量を必要とせず、せいぜい50～150NL/min程度であるが、得られる攪拌効果はVOD鋼での攪拌に匹敵すると報告されている¹⁷⁾。またこの操業ガス流量は、各ユーザーにおける導入期のトライアル結果ともよく一致していた。

5. 底吹き羽口の施工と交換方法

電気炉炉底部へ底吹き羽口を設置する方法をFig.8に示す。底吹き羽口の設置方法は、内装式と外装式の2つがある。内装式は電気炉炉内にてクレーンなど用いて設置する方式である。もう1つは外装式であり、あらかじめ底吹き羽口をフランジに据え付け、リフターを用いて上昇させ、フランジを固定する方式である。当社ではいずれの方式においてもメーカーであらかじめアSEMBルした一体品として提供でき、その結果現地での施工が簡略化され、作業工

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.

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 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 process¹⁷⁾. 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.

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

数を削減することが可能となっている。

外装式の交換方法の1例をFig.9に示す。交換手順は以下のとおり。

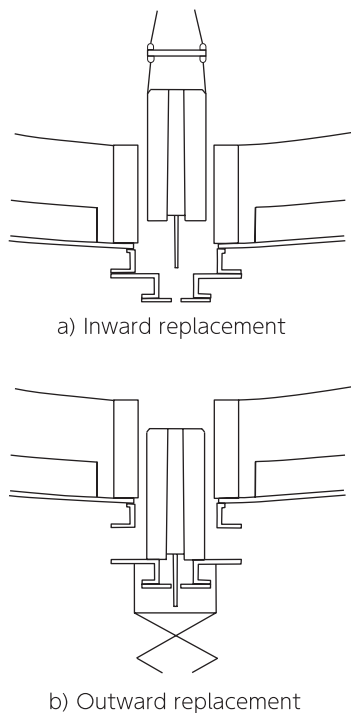


Fig. 8 Two methods for replacing bottom gas blowing tuyere assembly.

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.

- (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

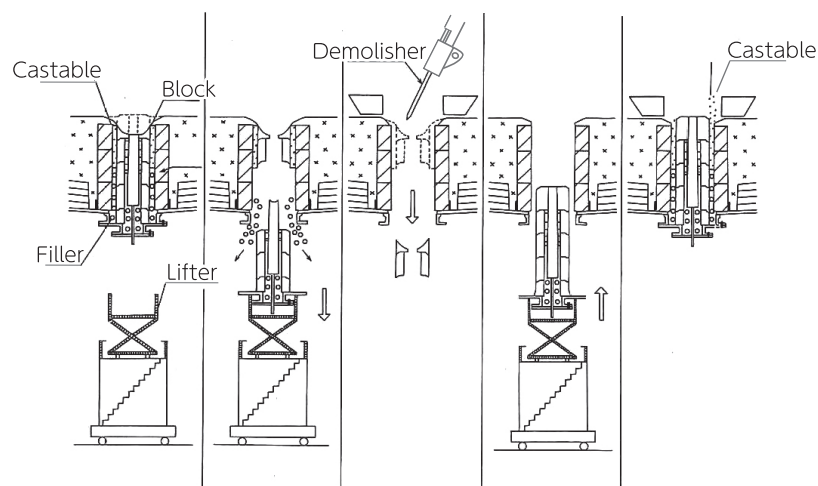


Fig. 9 An example of outward replacement of gas blowing tuyere assembly¹⁵⁾.

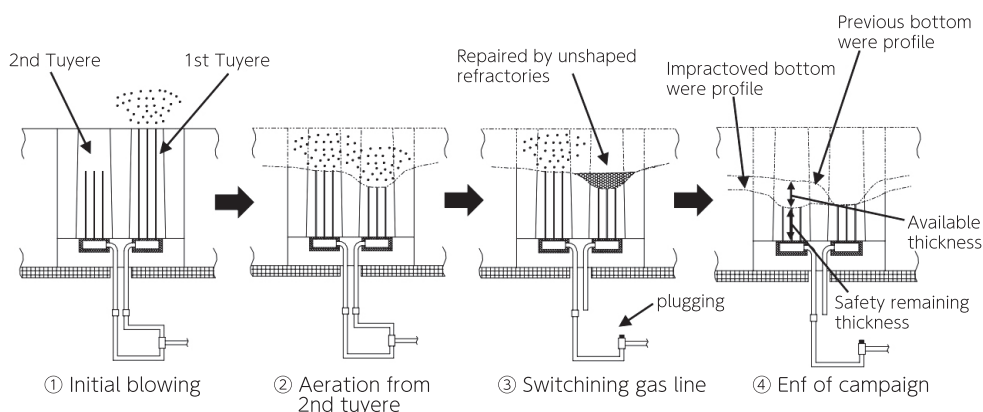


Fig. 10 Schematic diagram of the use of combination tuyere¹⁸⁾.

- ① リフターを設置，フランジを取り外す。
- ② フランジとともに底吹きプラグ本体を引き抜く。
- ③ 炉内に残留した羽口れんがを解体機で破壊し，炉下に落とす。
- ④ 新しい羽口をセットする。
- ⑤ 羽口と周辺れんがの隙間には焼結強度の低いフィラーを予め充填し，その後スタンプ材や流し込み材で施工し完了させる。

6. 当社独自の底吹きプラグ／羽口耐火物

6.1 コンビネーション羽口

底吹き羽口の損傷は，炉床一般部と比較し，ガス吐出による影響で一般的に大きくなる。電気炉の操業計画より羽口交換が困難となる場合，コンビネーション羽口¹⁸⁾が適用できる。コンビネーション羽口は，羽口に2本のプラグを埋設し，切り替えの可能なガス配管を有する。その使用方

of refractory gas purging plug cannot be conducted, a combination tuyere¹⁸⁾ 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 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 schematic 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 steel¹⁹⁾, (2) embrittlement induced by carburizing of C contained in MgO-C refractory

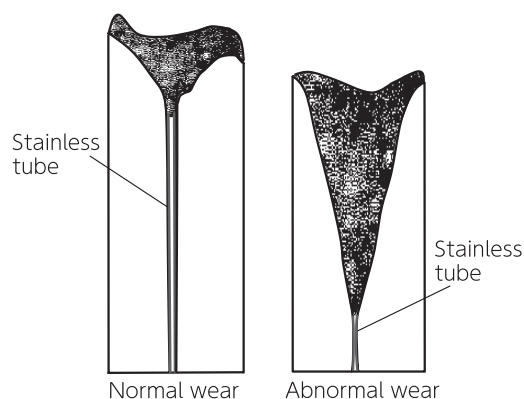


Fig. 11 Schematic illustration of bottom gas blowing tuyere severely worn by selective damage onto embedded stainless steel tube.

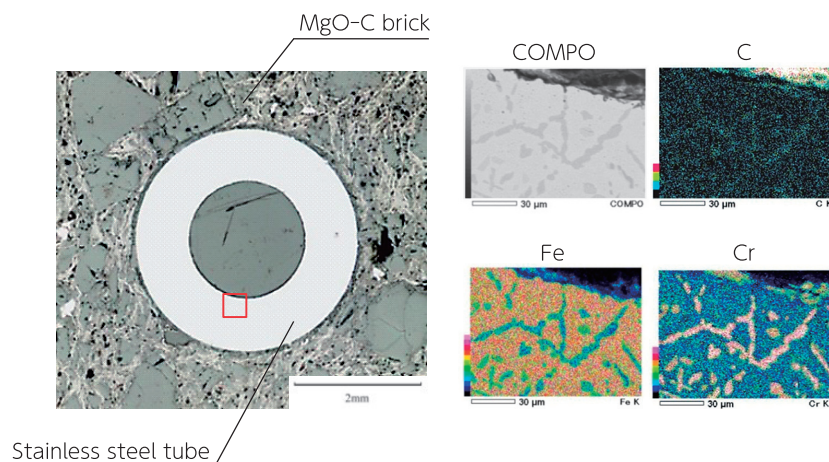


Fig. 12 Microphotograph and EPMA images of sensitized structure of stainless steel tube in MgO-C brick after heating at 1200°C.

法をFig.10に示す。まず1stプラグを使用し、損傷が進むと一定深さで埋設された2ndプラグの表面が露出する。1stプラグのガス吹きを停止し、熱間補修材等でプラグ表面を埋める。その後2ndプラグの寿命判定ラインまで、使用し寿命を全うする。コンビネーション羽口は、実操業での損傷速度、目標ライフ、ガス切り替えのタイミングを考慮し最適に設計される。

6. 2 ノンカーボンプレキャストプラグ

底吹き羽口の損傷は、ガス吹き込み時の加熱冷却による熱スポーリング損傷やスクラップ衝突による損傷に加えて、プラグ中に埋設されたステンレス細管の選択的損傷 (Fig.11) が律速となるケースも多く、その抑制も重要である。ステンレス細管の損傷原因は、① 溶湯による溶融¹⁹⁾、② 熱履歴による鋭敏化 (Fig.12)、③ カーボンの浸炭脆化などが考えられている。これらの防止のため、ステンレス細管の表面処理やノンカーボン材を保護管として金属細管に装着するなどの対策がとられている。プレキャストノズル用耐火物は、カーボンを含まないアルミナ質 (Table 1 に記載のCAM7(KGC)が代表品質) であり、保護管と同様の役割を果たし、細管の先行損傷を抑制できる。製造面から、CIP成形や一軸加圧成形により製造されるMgO-Cれんがと比較して、リードタイム、コスト面では有利であるため、今後構造改善やキャストブル材の改善等を継続していく。

7. 結言

電気炉底吹きプラグに関する耐火物技術とその施工方法、普及期におけるユーザー／メーカーによる底吹き攪拌

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

のラボ評価から試験運用結果まで紹介した。その技術は、当時の底吹き攪拌の多くの現場実験を元に確立されたものであり、その後、耐火物や操業技術の発展に合わせて現在の形となった。今後、カーボンニュートラルに向けた取り組みが開始され、電気炉操業における底吹き攪拌とその耐火物技術への要求の高まりによって、更なる改良・開発が必要になると予想される。

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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