

## Monolithic Refractories for EAF

Shigefumi NISHIDA\*<sup>1</sup>Daisuke TANAKA\*<sup>2</sup>Kiyoyuki KOMATSUBARA\*<sup>3</sup>

### Abstract

Recently, operating conditions of electric arc furnaces (EAFs) have become severe, not only because high quality steel is being produced but also because low grade steel scrap is utilized as a raw material. Development of monolithic refractories and precast blocks for EAFs have been progressing along with the change in operation. In this paper, features of our monolithic refractories and precast blocks for EAFs are comprehensively described.

### 1. Introduction

The electric arc furnace (EAF) is a batch processing facility that melts steel scrap by electric arc heating. Its flexible productivity enables the control of production level in accordance with fluctuation of steel demand as well as changes in product mix. Therefore, more than 30% of the crude steel is made by EAF in Japan. Moreover, the scrap supply in Asia is forecasted to continue to increase. Thus, the EAF process is regarded as one of the important steelmaking processes.

In recent years, the operating conditions of EAFs have become very harsh for refractories because of the intensive refining treatment required to produce clean steel and/or special steel from low grade scrap. Thus, it is important not only to use durable refractories but also to apply adequate repairing materials to ensure stable EAF operation. We have been continuing development and improvement of various monolithic refractories and precast blocks for EAFs in order to deal with the severe operating conditions. Figure 1 is a schematic view of the parts of the EAF where monolithic refractories and precast blocks are applied. In this paper, the features of monolithic refractories and precast blocks for the EAF are described.

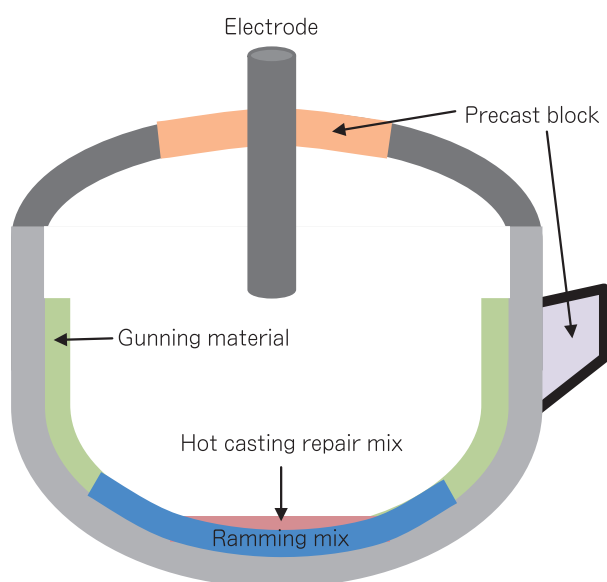


Fig.1 Outline of electric furnace.

### 2. Ramming Mixes for Hearth

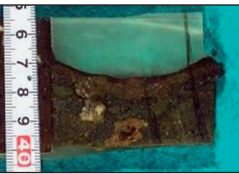
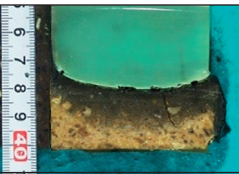


In many cases, magnesia ramming mixes are installed onto the refractory bricks of the EAF hearth where steel scrap and other raw materials are melted by electric arc. Since modern intensive steel refining treatment promotes hearth wear, further improvement in durability of refractories is required.

In order to reduce hearth refractories wear, application of dolomitic ramming mix which is specialized in spalling resistance and abrasion resistance is recommendable. Desirable characteristics are achieved by utilization of dolomite, which exhibits excellent sinterability, resulting in rigid structure formation. Figure 2 shows a cross sectional picture of a dolomitic ramming mix after the corrosion test compared to that of a magnesia ramming

\*<sup>1</sup> General Manager, Unshaped Refractories R&D Sec. No.2, Research Dept. No.2, Research Center

\*<sup>2</sup> General Manager, Unshaped Refractories R&D Sec. No.1, Research Dept. No.2, Research Center

\*<sup>3</sup> Assistant Manager, Unshaped Refractories R&D Sec. No.2, Research Dept. No.2, Research Center

Brand name	Dolomite material	MgO material
	SVP-D-218	SVP-M-971
Hot face		
Back side		
Corrosion depth	4mm	10mm

<Test conditions>  
 Rotating crucible method:1550~1600°C/3h Slag:C/S=1.0

Fig.2 Cross-section of samples after corrosion test.

Table 1 Properties of Ramming mixes

Brand name		Dolomite material	MgO material
		SVP-D-218	SVP-M-971
Chemical composition (mass%)	MgO	75	96
	CaO	20	1
	SiO <sub>2</sub>	<1	2
	Fe <sub>2</sub> O <sub>3</sub>	3	<1
Grain size distribution Max. size (mm)		8	5
Material requirement (t/m <sup>3</sup> )		2.80	2.65
Supply List		AC:150t,80t,140t DC:150t	AC:130t

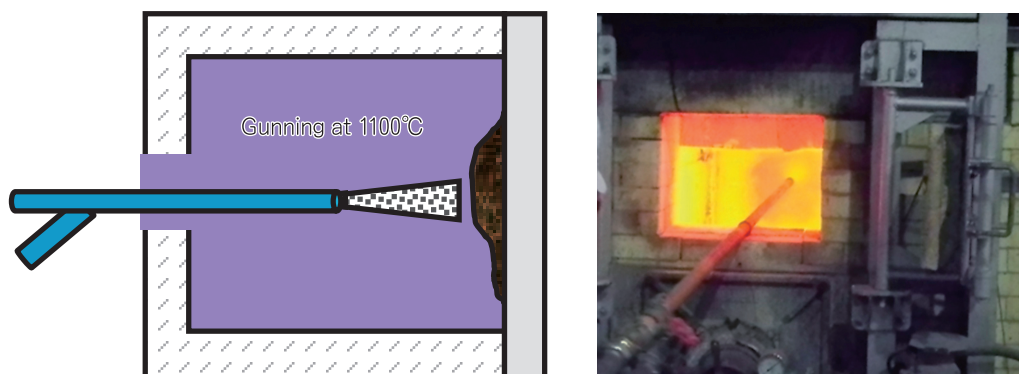


Fig.3 Diagram of large-sized examination furnace.

mix. It is obvious that the dolomitic material shows less slag penetration and corrosion degree than the magnesia material. The representative properties of magnesia material SVP-M-971 and dolomitic material SVP-D-218 are summarized in Table 1.

### 3. Gunning Mixes

The inner wall of electric furnaces is damaged by the following mechanisms; corrosion attributed to excessively high of arc and/or molten steel temperature, dissolution in corrosive slag, and abrasion caused by mechanical shock induced by scrap feeding. The worn areas are generally repaired by high corrosion resistance gunning material. In addition, since the gunning repair has to be completed during the short intervals between tapping and charging, excellent adhesion under high temperature installation conditions is essential so as to inhibit peeling-off.

In order to accurately evaluate the adhesion status of

gunning mixes that were installed under extremely high temperature conditions, we created equipment for large scale hot gunning experiments that can reproduce the actual gunning status as shown in Fig.3. Our product attired excellent adhesiveness under hot gunning conditions of in commercial application through the gunning experiments performed at temperatures exceeding 1100°C utilizing the equipment. Moreover, it also has excellent workability, which is a result of a wide tolerance range for the amount of mixing water.

We have wide lineup of gunning mixes so that a mix suitable to the individually varied EAF operating conditions can be selected. Table 2 exemplifies the typical properties of three gunning mixes, which show sufficient successful application results. Magnesia gunning mix JTM-M-371 is the standard material with general versatility. Dolomitic JTM-MD-57 and magnesia-siliceous JTM-MX-19 are materials with high corrosion resistance

**Table 2 Properties of gunning materials**

Brand name		Dolomite material	MgO material	MgO·SiO <sub>2</sub> material
		JTM-MD-57	JTM-M-371	JTM-MX-19
Chemical composition (mass%)	MgO	64	87	54
	CaO	25	6	3
	SiO <sub>2</sub>	4	2	37
Grain size distribution Max. size (mm)		5	3	3
Physical properties	1000°C-3h	25	29	25
	1500°C-3h	24	26	24
Grade		High	Middle	Low
Supply List		AC : 90t	AC : 130t, 150t, 70t, 40t DC : 110t, 60t	AC : 130t, 150t DC : 60t

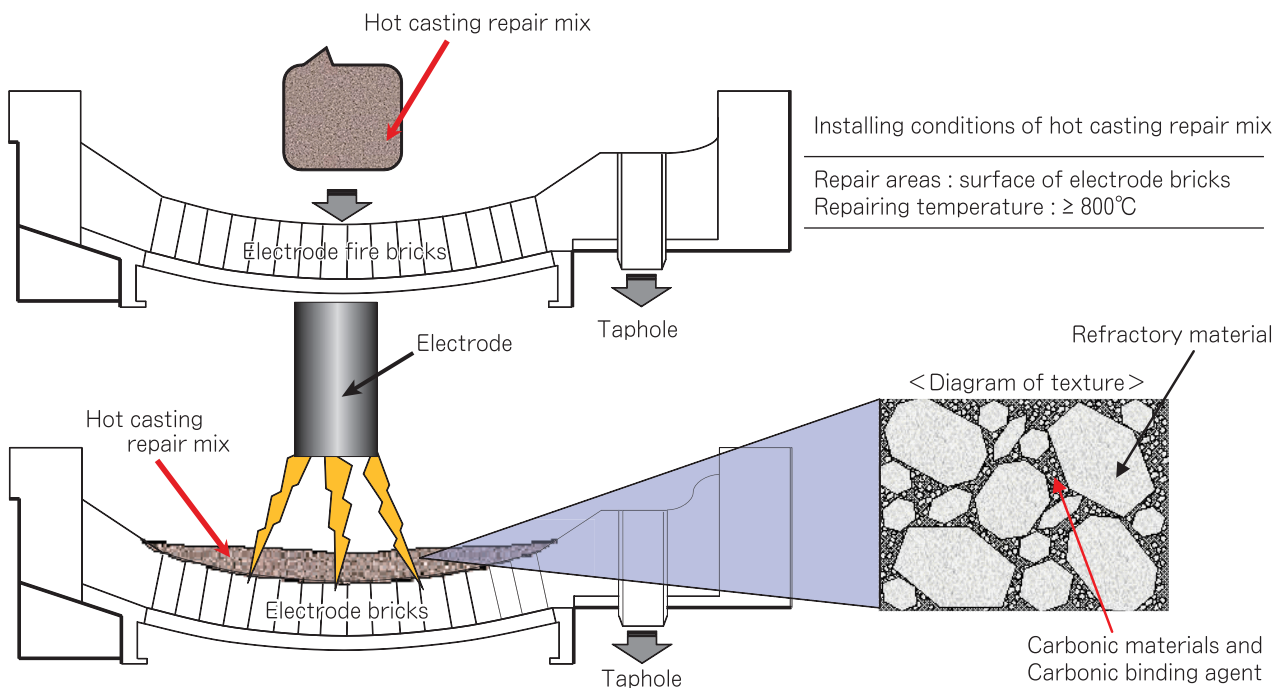
and high density, respectively. Those materials have been satisfactorily applied to commercially operated EAFs.

**4. Hot Casting Repair Mixes**

In general, the EAF hearth is repaired by ramming or gunning materials during the intervals between tapping and charging. Since those materials are electrical insulators, electrical conductivity is required for materials used to repair the anode bricks embedded in the hearth of direct current (DC) EAFs as shown in Fig.4.

Furthermore, durability is also necessary since they suffer from extremely high temperature electrodes during conduction and are exposed not only to molten steel during melting and refining but also to slag during discharging.

Therefore, we developed carbon-bonded hot casting repair mixes in order to deal with the requirements. Superior durability of materials is appreciated in many EAFs. Thanks to the suitably arranged carbonaceous materials, these hot casting repair mixes show good



**Fig.4 Schematic diagram of hearth repair of DC-EAFs.**

**Table 3 Properties of new quick hardening hot casting repair mix**

Brand name		FRX-M70-D3	FRX-A80-D11
Chemical composition (mass%)	MgO	64	24
	Al <sub>2</sub> O <sub>3</sub>	—	42
	C	20	20
	Grain size distribution Max. size (mm)	5	20
Cast at 1000°C			
Apparent porosity(%)		26.6	26.6
Bulk density(-)		2.51	2.50
Adhesion strength(MPa)		2.0	1.9
Hot flowability(mm)		219	230
Hardening time(min)		4.8	4.2
Supply List		AC : 60t DC : 60t	AC : 70t,20t DC : 60t

electrical conductivity as well as poor wettability to molten slag, resulting in excellent corrosion resistance. Additionally, the materials are designed to maintain self-fluidity under high temperature for a longer time. Therefore, they spread widely on the hearth and completely fill the damaged rough surface followed by tight adhesion that ensures high adhesive strength.

According to the above desirable characteristics, they are also suitable for following applications; repair of hearth itself, filling gaps around EBT tube during EBT tube installation, and repair of peripheral area of EBT tube. The typical properties of the carbon-bonded hot casting repair mixes are summarized in Table 3. Magnesia FRX-A80-D11 is the base material with general versatility. FRX-M70-D3, which is the material developed on the bases of FRX-A80-D11, shows excellent corrosion resistance particularly for low basicity slag.

## 5. Precast Blocks for Furnace Lid

The EAF lid is comprised of a central small ceiling part and circumferential large ceiling part. In the past, high alumina ramming mixes were widely used for the small ceiling part and silica bricks or unburned magnesia-chrome bricks were widely used for the large ceiling part. Nowadays, refractories are generally used only for small central ceiling part because water cooling technology has been applied to the periphery.

As refractories for the small central ceiling part, chrome-containing aluminous precast blocks are widely

**Table 4 Properties of precast blocks for EAF lid**

Brand name		CST-A72PB	CST-A720PB	CST-A780PB
Chemical composition (mass%)	Al <sub>2</sub> O <sub>3</sub>	79	77	77
	SiO <sub>2</sub>	19	18	10
	Cr <sub>2</sub> O <sub>3</sub>	—	3	10
Linear change (%)	110°C-24h	-0.03	0.00	0.00
	1000°C-3h	-0.10	-0.20	-0.03
	1500°C-3h	+0.30	+0.45	+0.15
Modulus of rupture (MPa)	110°C-24h	5.9	6.9	4.5
	1000°C-3h	11.8	9.8	10.5
	1500°C-3h	14.7	14.7	11.0
Cold crushing strength (MPa)	110°C-24h	33.3	25.5	25.0
	1000°C-3h	65.7	58.8	60.0
	1500°C-3h	73.5	112.8	75.0
Apparent porosity (%)	110°C-24h	16	13	15
	1000°C-3h	17	16	18
	1500°C-3h	17	17	18
Supply list		A : 85t B : 20t	B : 100t B : 20t	B : 100t

applied due to high corrosion resistance and superior thermal shock resistance. We have various lineups of refractories for the small ceiling part as well as large ceiling part in order to adjust the properties for individually varying operating condition. The typical properties of successfully applied precast blocks for the EAF lid are provided in table 4. CST-A72PB (high alumina) shows superior thermal shock resistance. CST-A720PB (chrome-including alumina) is used in many actual EAFs because of superior corrosion resistance and thermal shock resistance.

## 6. Taphole Clay

Along with the blast furnace (BF), taphole clay is used for plugging the molten metal tapping hole of the gasification melting furnace, nonferrous metal refining furnace and ferroalloy smelting EAF. Table 5 shows the typical properties of taphole clays for ferroalloy smelting EAFs and BFs. The taphole clay for BFs has been improved to achieve high strength and low apparent porosity in accordance with increase in productivity associated with enlargement of BF inner volume, which tends to intensify the load to taphole clay. Furthermore, applying silicon nitride as raw material achieves long tapping time in BFs, resulting in lower unit consumption of taphole clay. On the other hand, taphole clay for uses other than the blast furnace exhibits lower strength and higher apparent porosity since it generally includes a large

**Table 5 Properties of taphole clay for electric arc furnace and blast furnace**

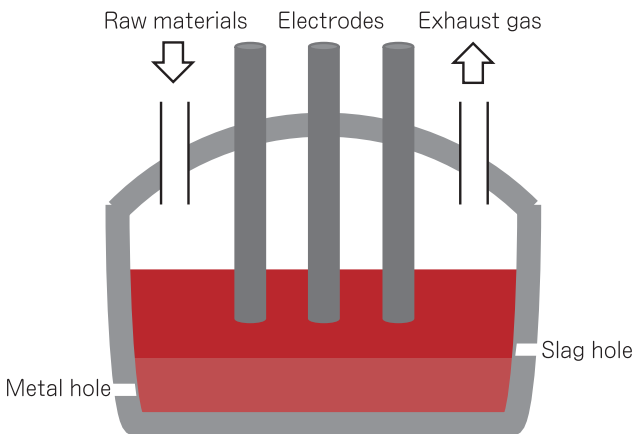
Brand name		CAM-CC-4	CAM-AS-14	CAM-AA-3	CAM-AN-28
Application for		Slag hole	Metal hole		Blast furnace
Chemical composition (mass%)	Al <sub>2</sub> O <sub>3</sub>	13	35	34	25
	SiO <sub>2</sub>	41	6	6	14
	C	24	16	17	14
	SiC	—	19	19	28
	Special additives	—	10	10	—
Cold crushing strength (MPa)	1500°C-3h	12.6	17.6	18.2	41.3
Apparent porosity (%)	1500°C-3h	29.6	35.8	35.5	23.7
Bulk density (-)	1500°C-3h	1.61	1.91	1.92	2.22
Remarks				Improved spreading property	

amount of binder. These features are necessary for EAF taphole clays since the ability of the mud-gun and drilling machines used with EAFs are poorer than those for BFs. Therefore, we designed a material focusing on stable injection and easy drilling properties.

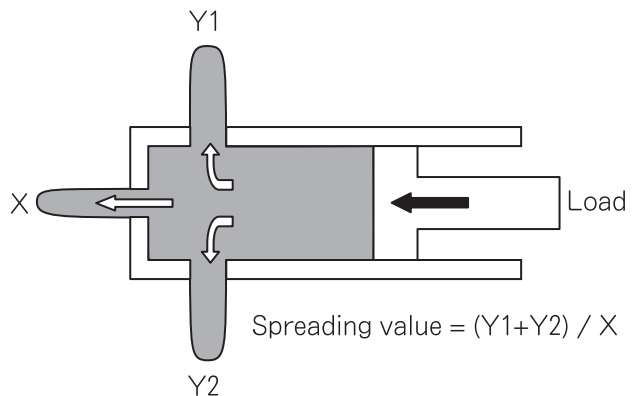
Ferrous alloy smelting EAFs have a separate metal taphole and slag taphole (Fig.5). Unlike blast furnace operation, molten slag and metal are discharged from the slag taphole and metal taphole, respectively. Therefore, taphole clay should be suitably selected for each taphole. For the slag taphole, carbon-rich siliceous material is suitable in order to achieve sufficient slag drainage efficiency as well as slag corrosion resistance. On the other hand,

alumina-rich material, which is superior in metal corrosion resistance, is suitable for the metal taphole. However, it is difficult to keep a stable taphole length because nothing prevents taphole clay from floating up by buoyancy, just like the coke packed layer in a BF hearth. Hence, serious damage of wall brick around the molten metal entry point occasionally occurs.

In order to deal with this issue, CAM-AA-3, which has improved spreadability in the furnace after injection, was used in an actual EAF. As a result, the taphole length became longer and more stable than that of conventional taphole clay CAM-AS-14. The evaluation method and results of spreadability are shown in Figs. 6 and 7,



**Fig.5 Schematic illustration of electric arc furnace for ferroalloy.**



**Fig.6 Schematic illustration of spreading property measurement.**

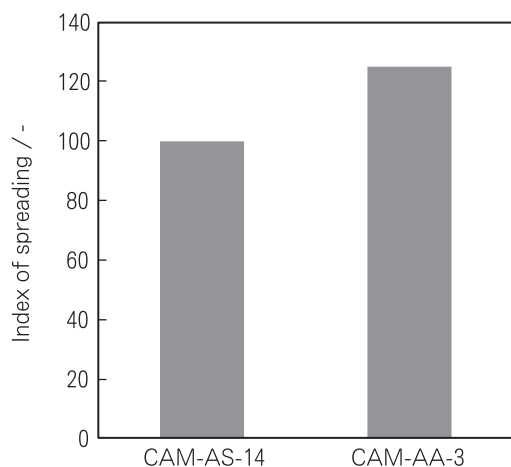


Fig.7 Index of spreading for CAM-AA-3 based on CAM-AS-14.

respectively. Spreadability is evaluated by the discharged weight ratio of injection direction and perpendicular direction, i.e.,  $(Y1+Y2)/X$ . A large value of this ratio means it is a material with good spreadability.

## 7. EAF Launder

As for EAF launder material, abrasion resistance and thermal spalling resistance are required as well as

corrosion resistance. EAF launder mainly consists of  $Al_2O_3$ -SiC-C material and is supplied as bricks, precast blocks and HARTROCK which is high density precast blocks. Table 6 shows the typical properties of precast blocks for EAF launder. CST-AT-319PB, which contains a larger amount of alumina and carbon, shows superior corrosion resistance and spalling resistance. High corrosion resistance is achieved by increasing the amount of alumina and increase in carbon content suppresses excessive sintering, resulting in improvement of spalling resistance.

By application of this material to a commercially operated EAF launder, considerable improvement in durability was recognized in comparison with conventional material CST-AL-15PB. In addition,  $Al_2O_3$ -SiO<sub>2</sub> precast block CST-A6321PB and  $Al_2O_3$ -Cr<sub>2</sub>O<sub>3</sub> precast block CST-A8165PB also achieved a longer service life in commercial application because of their excellent corrosion resistance and thermal spalling resistance. Moreover, it is advantageous for precast blocks and HARTROCK to be applicable in various shapes, e.g., whole launder monoblock, without property fluctuations since they are made of monolithic refractories.

We will continue to suggest suitable material according to customer requirements. We remain flexible in thinking, and try to remain free from conventional ideas when designing materials and shapes.

Table 6 Properties of precast blocks for EAF launder

Brand name		CST-AL-15PB	CST-AT-319PB	CST-A6321PB	CST-A8165PB
Chemical composition (mass%)	Al <sub>2</sub> O <sub>3</sub>	70	75	72	77
	SiO <sub>2</sub>	9	2.5	22	—
	SiC	15	15	—	—
	C	2	3	—	—
	Cr <sub>2</sub> O <sub>3</sub>	—	—	—	20
Linear change (%)	110°C-24h	-0.03	-0.02	+0.03	—
	1000°C-3h	0.00	-0.01	-0.25	—
	1500°C-3h	+0.80	+0.18	+0.51	—
Modulus of rupture (MPa)	110°C-24h	8	6	15	8
	1000°C-3h	4	5	20	24
	1500°C-3h	11	7	17	28
Apparent porosity (%)	110°C-24h	15.6	14.7	12.9	11.0
	1000°C-3h	22.7	15.6	16.9	15.9
	1500°C-3h	20.8	15.7	18.4	17.3
Bulk density (-)	110°C-24h	2.80	3.09	2.67	3.41
	1000°C-3h	2.70	3.06	2.63	3.38
	1500°C-3h	2.68	3.06	2.61	3.31

## 8. Conclusion

In this article, the developed monolithic products and precast blocks for EAFs were introduced. From the viewpoint of energy and the environment in Japan, it is natural to assume that innovation in EAF processing technologies will continue for the purpose of efficiency improvement and utilization of various kinds of steel scrap

as raw materials. Further development of the refractories is required in order to optimize properties for the various operating conditions. Monolithic refractories for EAF initial linings and repair materials should play important roles. We will continue to develop and improve not only material but also the installation method to ensure stable EAF operation.