Introduction to Carbon Free Refractory Lining for Ladle Steel Bath in EAF Steel Mill

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Abstract

It is prospected that, in accordance with the progress of environmental and ecological activities connected with achieving carbon neutralization by 2050, the ratio of steel production by electric arc furnace (EAF), which is characterized by a smaller amount of CO_2 emission, will increase in the steel industry. Consequentially, production of high-grade steel products would increase in EAF steel mill, resulting in intensification of secondary refining treatments in the teeming ladle to guarantee steel qualities. Since teeming ladle refractories are severely damaged by intensive secondary refining, Al_2O_3-MgO-C brick is usually applied. As an alternative teeming ladle refractory, Al_2O_3-MgO refractory with superior corrosion resistance are introduced in this article as carbon free refractory for steel bath in teeming ladle in which intensive secondary refining is conducted. In practice, according to teeming ladle operational conditions, ALTIMA unburnt Al_2O_3-MgO brick, Al_2O_3-MgO castable refractories and precast block fabricated with Al_2O_3-MgO monolithic refractory can be used in combination.

By applying carbon free refractories with low thermal conductivity for the steel bath in the teeming ladle, suppression of heat radiation from the teeming ladle steel shell results in the reduction of CO_2 gas emission in EAF operation is expected along with prevention of molten steel contamination by the C component contained in refractories. In the case where a teeming ladle is relined with castable refractories, reduction of teeming ladle refractory unit consumption is expected by adopting partial additional repair work along with reduction of waste disposal. Because of such advantageous characteristics, carbon free refractories are practically applied for teeming ladle in several steel mills.

1. Introduction

Restraint of further climate change is a worldwide challenging task to be achieved. It is well recognized that the major factor for climate change is global warming caused by increasing emission of greenhouse gasses, among which, due to its remarkably large amount of emission, CO_2 gas has had the biggest influence on climate change. Based on this recognition, more than 120 countries and regions including Japan adopted worldwide activity to achieve carbon neutralization composed with equivalent balance between emission and absorption of CO_2 gas until the middle of this century. Among Japneses industrial sectors, the steel industry emits the langest amount of CO_2 gas, which occupies 14 % of total emission. Recently, Japanese steel producers published activities to achieve carbon neutralization until 2050, which includes a production shift from conventional blast furnace - converter furnace process to electric arc furnace (hereinafter referred to as “EAF”) process, as well as technical developments for high grade steel production in a large scale EAF mill. It has been reported that CO_2 gas emission in the EAF process, in which steel products are produced from steel scrap, can be reduced to roughly one-quarter (1/4) of that of the conventional blast furnace process in which iron ore is reduced by coal-derived coke[1]. It is inferred that, when high grade steel products are produced in an EAF mill, secondary refining in the teeming ladle represented by the ladle refining (hereinafter referred to as “LF”) process, of which the treatment method is schematically illustrated in Fig. 1, would be intensified. Since teeming ladle refractories are severely damaged under such operational conditions, better durability as well as easier repairing method for damaged teeming ladle refractories would be necessitated. Furthermore, the possibility of molten steel contamination by teeming ladle refractories

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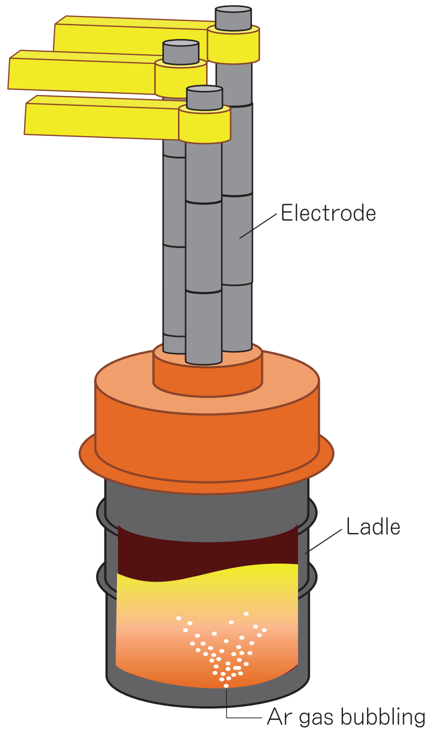

Fig. 1 Schematic illustration of Ladle Furnace (LF).

needs to be minimized in order to guarantee steel quality. Since the major purpose of the production shift to EAF mill is reduction of CO_2 gas emission, reduction of heat loss from the teeming ladle body is another important issue for reducing energy consumption in the steelmaking process.

Our group has been providing a variety of refractory products which are applied as work linings or heat insulation refractories in various furnaces or vessels in steel, cement, incineration or other high temperature environment industries. This is in association with the development of refractory products characterized by low thermal conductivity or lightweight thermal insulation material which could contribute to reduction of heat loss at customers' site[2-4]. Another article in this technical report[5] and the other[6] mention the heat insulating materials for the teeming ladle lids that have a favorable effect on reducing heat loss from the molten steel. Focusing on the teeming ladle in the EAF steel mill where intensive secondary refining is conducted, various types of carbon free refractory material which could contribute to securing durability as well as the reduction of heat loss are introduced in this article.

2. Reduction of Heat Loss from Teeming Ladle by Carbon Free Refractory Relining in Steel Bath

2. 1 Heat loss from teeming ladle

Molten steel tapped from the EAF is refined in the multistage secondary refining process and cast into semi-products in continuous caster. During such a process, molten steel temperature is gradually lowered because of heat loss from the teeming ladle. Taking into account such molten steel temperature drop, the tapping temperature from the EAF and heating up of molten steel temperature in LF process is determined. When heat loss from the teeming ladle is suppressed, energy consumed in the EAF and/or LF process can be lowered in association with reduction of CO_2 gas emission.

One estimation example of the dissipation of thermal energy stored in molten steel in the teeming ladle is shown in Fig. 2. Heat loss from the teeming ladle, more exactly, dissipation of thermal energy stored in molten steel can be broken down into three manners, ① heat radiation from the slag surface in the teeming ladle, ②

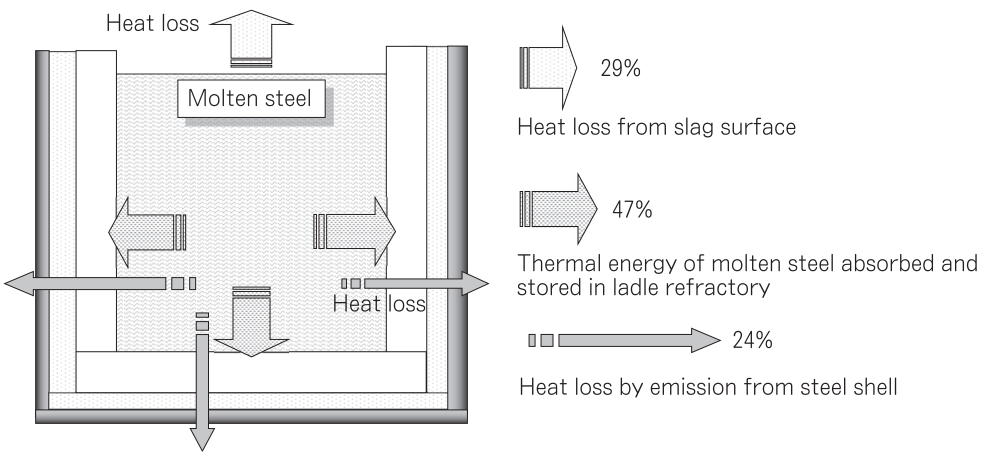

Fig. 2 Three manners of thermal energy loss from molten steel in teeming ladle[6].

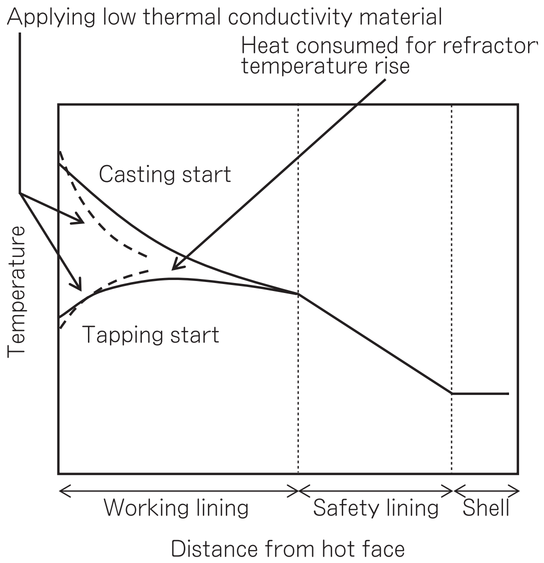

Fig. 3　Schematic diagram of temperature distribution change in ladle refractories with different thermal conductivity.

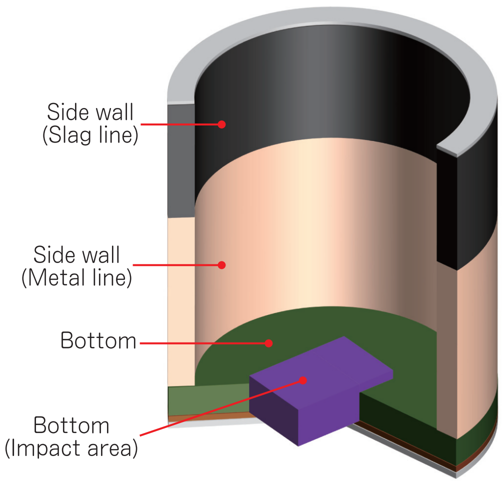

Fig. 4　Typical refractory linings for teeming ladle.

emission of heat conducting through relined refractory from teeming ladle steel shell and ③ heat absorbed and stored in relined refractories from molten steel. In order to minimize heat radiation from the slag surface, putting teeming ladle lid until casting completion and improving lid putting rate is effective. In addition, it is prospected that light weight low thermal conductivity lid material with sufficient durability will be necessitated. Thermal insulation refractory material is often used between the steel shell and the work lining in order to reduce heat emission from the teeming ladle steel shell. In cases where intensive secondary refining is conducted in the teeming ladle, such an arrangement could accelerate the wear rate of the working refractories. Furthermore, since the thermal insulation efficiency of applied thermal insulation refractory material can be worsened under repeated severe operational conditions, exchanging repair work is required by demolishing working refractory materials that are still in a good condition, in other words, waste disposal of used refractories is increased. On the contrary, as per Fig. 3, in which the change in temperature distribution in relined ladle refractories with different thermal conductivities equaled by receiving molten steel during casting operation is schematically illustrated, applying a lower thermal conductivity refractory for the working lining is effective for lowering heat loss by heat absorption and storage in the relined refractory[4,8]. Applying a carbon free refractory for the teeming ladle is categorized as this heat loss reduction measure.

2. 2　Carbon free refractory relining in teeming ladle metal line

A typical refractory lining configuration for the teeming ladle is illustrated in Fig. 4. In general, teeming ladle refractories consist of a ladle bottom refractory, an impact zone refractory which is exposed to direct attack of molten steel tapped from the EAF, and a steel bath refractory which contacts molten steel and a slag line refractory. In cases where pyrophyllite or high-alumina brick is applied for the steel bath in a teeming ladle operated in an EAF mill where intensive secondary refining is applied, the relined refractories are severely damaged. For this reason, Al_2O_3-MgO-C and MgO-C brick are usually relined for bottom, steel bath and slag line. Benefits of a durable carbon free refractory lining are discussed while considering on such teeming ladle refractory configuration.

For the carbon-free steel bath lining, specially designed Al_2O_3-MgO refractories with excellent corrosion resistance are used instead of conventional Al_2O_3-MgO-C bricks in the bottom and the steel bath in a ladle. The application of the Al_2O_3-MgO lining is expected to provide the following benefits, i.e., (1) lower heat loss because of low thermal conductivity, (2) no concern for carbon contamination of molten steel and (3) better durability. Comparing with conventional refractory relining configuration, several examples of teeming ladle relining configuration composed in a combination of brick, precast block or on-site relined castable material of carbon free refractory are suggested in Fig. 5. The on-site casting ratio is enlarged with an order of Type A, B, C and D.

In type-A, the ladle wall is relined with unburnt

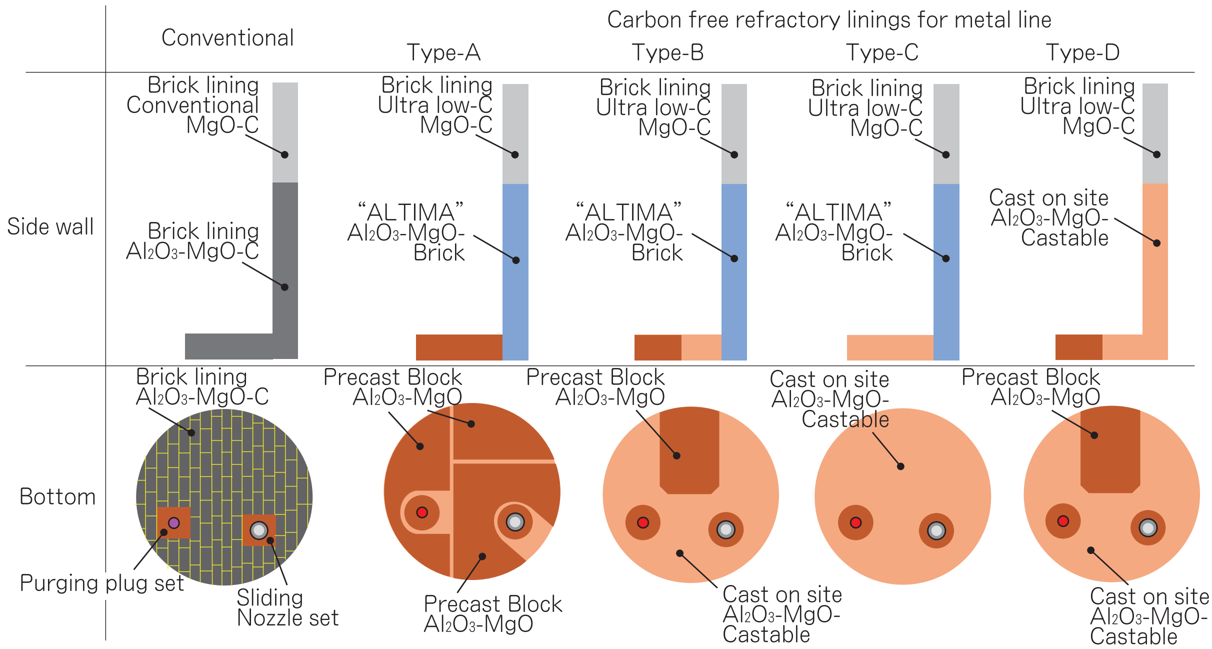

Fig. 5 Several examples of relining configurations with carbon free refractory in teeming ladle.

Al_2O_3-MgO brick ALTIMA[2,9-10] and a major part of the ladle bottom is relined with a few pieces of large-sized precast block associated with on-site casting for the well block periphery and a part of the bottom circumference. Because of the small quantity of castable refractory material used at the site, a small capacity mixer suffices at the on-site casting operation. In addition, since the drying procedure for a relined teeming ladle does not require a high level of cares, a large investment cost is not necessary for installation of on-site casting facilities such as large capacity mixers or fuel gas burners for drying. In type-B, a major portion of the ladle bottom is relined with castable refractory except for the impact zone where highly densified precast block is adopted, and the ladle wall is relined with ALTIMA. In cases where relatively a large capacity mixer is available along with transportation facilities for castable refractory mixtures such as hoppers and shooters, relining work can be completed in a short time. In type-C, in which the whole ladle bottom is relined with castable refractory material, relining work can be conducted in shorter time because of no additional time for setting the impact zone precast block.

In type-D, in which the whole ladle bottom and wall are relined with castable refractory material except for the impact zone where highly densified precast block is adopted, molds used for ladle wall relining and mixers with sufficient capacity to deal with a large amount of castable refractory material are necessitated. In addition, the heat quantity received for drying completely relined castable refractories is increased. While, the complete castable refractory relining method enables partial additional relining repair work on damaged refractories with minimized demolished area. By applying such repairing procedure, teeming ladle maintenance can be scheduled flexibly so as to synchronize adequately with overall EAF operation in association with reduction of teeming ladle refractory unit consumption as well as of waste disposal.

Characteristics of each carbon free refractory for the teeming ladle steel bath are discussed in the following section.

3. Carbon Free Refractory for Teeming Ladle Steel Bath

3. 1 Distinctive characteristic of Al_2O_3-MgO refractory

Unburnt Al_2O_3-MgO material is the most suitable and selectable refractory for the carbon-free lining of ladle steel bath area. It was developed as a castable mix in the process of changing from shaped brick linings to monolithic linings at domestic integrated steel works in the late 1980s, and is still being optimized today.

At elevated temperatures which is created by heat transfer from molten steel to relined refractories in teeming ladle operation, the Al_2O_3 and MgO in unburnt

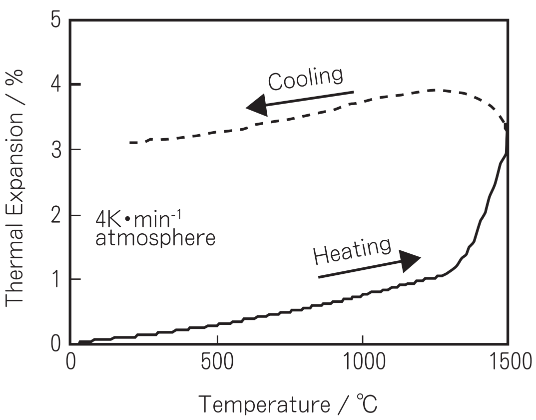

Fig. 6　Thermal expansion curve of unburned Al_2O_3–MgO refractories.

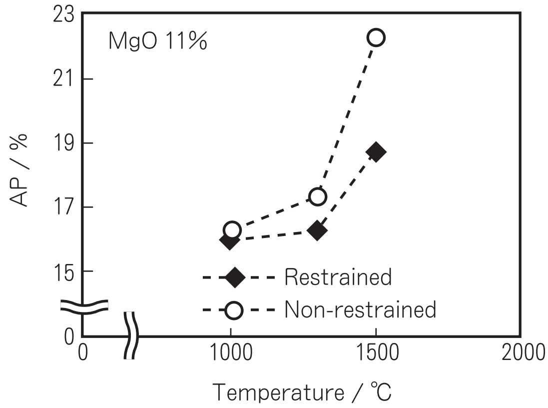

Fig. 7　Temperature dependence of apparent porosity of Al_2O_3–MgO refractories after being fired under restrained and unrestrained conditions.

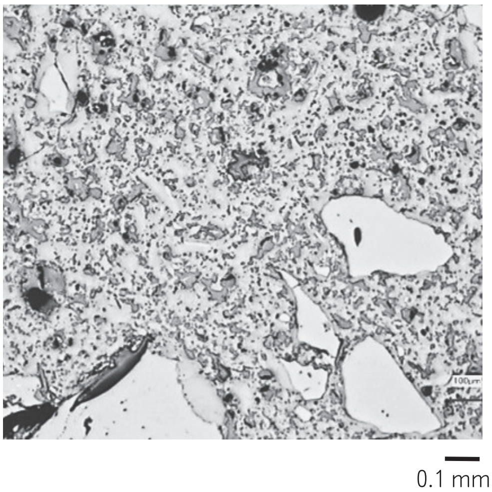

Fig. 8　ALTIMA microstructure with high complexity after heating at 1500 ℃.

refractory material mutually react and form spinel phase. Spinel phase formed by in-situ reaction functions to densify the refractory matrix structure and reinforce bonding between particles, resulting in improved durability. As indicated in Fig. 6, thermal volume expansion is associated with spinel formation. Under mechanical restraint conditions like relined refractories in the teeming ladle, as shown in Fig. 7, such thermal volume expansion contributes to densification of refractory structure and improvement of corrosion resistance and structural spalling resistance[11].

3. 2　ALTIMA unburnt Al_2O_3–MgO brick

ALTIMA is unburnt Al_2O_3–MgO brick for which Al_2O_3–MgO castable refractory relating technologies have been applied[2, 9–10]. High pressure pressing achieves densely packed structure. ALTIMA F023 has been developed by optimizing sintering agent addition and particle size distribution in the brick. During operation, the original brick structure is changed to the high complexity microstructure associated with low porosity and small pore diameter as shown in Fig. 8 by heat received from molten steel. Since smooth mass transfer in brick body is suppressed by such structure change, the brick wear rate is markedly lowered. Because of such advantageous characteristics, ALTIMA is broadly applied for the teeming ladle in EAF steel mills. The major chemical and physical properties of ALTIMA are summarized in Table 1.

3. 3　Al_2O_3–MgO castable refractory material

As shown in Fig. 9, the corrosion resistance and slag penetration resistance of the cast body have been improved by minimizing water fraction admixed at the relining site for securing cast body durability[12]. HiDeC, which was developed by adopting adequate dispersing agent and optimizing particle size distribution[13] so as to be relined with minimized admixed water has been contributing to the extension of teeming ladle refractory service life in many integrated steel works. It is noted that superior durability of HiDeC cast body depends on careful and skillful relining technologies, such as adequate control of setting behavior of the castable refractory mixture, intensive vibration casting and appropriate drying/preheating procedures, suitable for the intended material design.

On the other hand, for usage conditions that do not require as high a performance as HiDeC, SSC (Super-Shiro-Cast) series Al_2O_3–MgO castable are overall more suitable, considering various aspects such as not requiring strict relining management[13]. It was intended

Table 1 Chemical and physical properties of ALTIMA

Code	ALM-F023 "ALTIMA"
Material	Al_2O_3-MgO
Chemical composition / %	
MgO	88
Al_2O_3	7
F.C.	-
Apparent porosity / %	10.0
Bulk density	3.40
Cold crushing strength / MPa	59
Application	Metal line

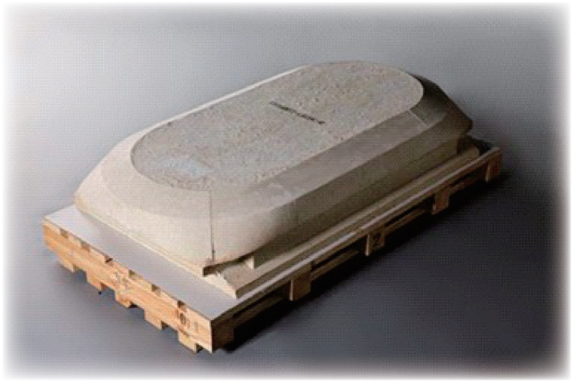

Fig. 10 Overall appearance of impact zone precast block.

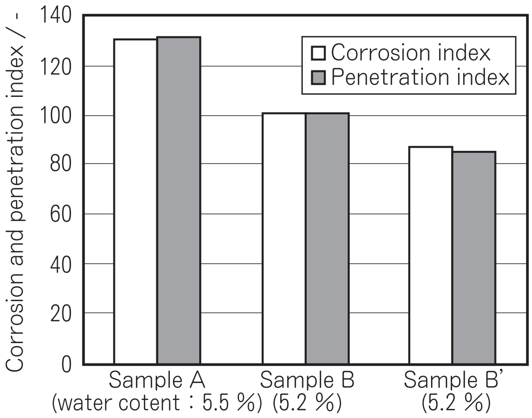

Fig. 9 Influence of mixing water fraction on corrosion and slag penetration resistance of Al_3O_3-MgO castable.

in the material design of SSC, that castability of the water admixed castable refractory mixture, i.e., the working time with proper fluidity and setting time would not depend so much on temperature. Because of such insensitivity to ambient temperature which varies with geographical district or relining site, SSC relining work can be performed steadily throughout the year without delicate adjustment of additives except for discriminative relining conditions such as severely cold climate environments.

3. 4 Precast block

Precast block is a castable refractory product which is fabricated by casting into a specified shape at the refractory manufacturing plant. Since the casting and drying operations are conducted in well managed conditions, large sized complex shape precast blocks, relined with an extremely low water admixed castable refractory such as HiDeC, can be produced. As an example, the overall appearance of precast block applied to the impact zone of a teeming ladle, which tends to be locally damaged, is shown in Fig. 10. If so required, the whole teeming ladle bottom can be relined or assembled with a few pieces of large sized precast block. In accordance with teeming ladle bottom area, two or three precast blocks are prepared for ease of transportation as well as assembly work.

3. 5 Low C MgO-C brick for slag line

Teeming ladle refractory service life is frequently regulated by the wear rate of its slag line refractory. MgO-C brick containing a certain amount of carbon component is usually applied as teeming ladle slag line refractory when putting first priority on suppression of slag line refractory damages induced by corrosion by molten slag and/or thermal spalling. Even though the slag line refractory does not contact directly with molten steel for long time, applying low C or ultra-low C MgO-C brick is desirable for minimizing molten steel contamination by the C component contained in refractories as well as for heat loss reduction[14]. The typical chemical and physical properties of low C and ultra-low C MgO-C brick are shown in Table 2.

4. Evaluation of Heat Loss Reduction by Carbon Free Refractory Relining

The effect of carbon free refractory relining on reduction of heat loss from the teeming ladle is evaluated by unsteady heat transfer analysis on a teeming ladle model of which the configuration is schematically illustrated in Fig. 11 along with major dimensions. Heat transfer analysis calculation is conducted on an axisymmetric teeming ladle model relined with 10 % C containing

Table 2 Chemical and physical properties of low and ultra-low carbon MgO–C bricks for ladle slag line

Code	MGT–1BS167	MGT–1BS187
Material	MgO–C (Ultra low C)	MgO–C (Low C)
Chemical composition / %		
MgO	95	92
Al_2O_3	-	-
F.C.	1.5	4.5
Apparent porosity / %	5.3	4.9
Bulk density	3.15	3.14
Cold crushing strength / MPa	64	55
Application	Slag line	Slag line

Al_2O_3–MgO–C brick or carbon free Al_2O_3–MgO brick. The bulk density, thermal conductivity and specific heat of relined working brick refractories at a typical temperature are summarized in Table 3. It is noted that the major physical properties of molten steel, permanent brick and teeming ladle steel shell is assumed to be constant and their specific values are omitted in this article. A schematically illustrated operation cycle of the teeming ladle used for heat transfer calculation and its time schedule is shown in Fig. 12 and Table 4, respectively. It was hypothesized that 1600 ℃ molten steel was tapped from the EAF to the teeming ladle and molten steel was reheated up to 1600 ℃ during LF operation so as to compensate for the temperature drop. The change of molten steel surface level in the teeming ladle at tapping and during casting operation was not taken into account. Instead, it was hypothesized that the teeming ladle was instantly filled with molten steel and emptied respectively during tapping and at end of casting. It was also hypothesized that the teeming ladle is covered with a teeming ladle lid throughout the casting operation. From the results of the calculations, it was confirmed that the heat balance between the heat radiation from the molten steel and the heat storage in the refractory material was balanced after 9 cycles, and the temperature change of the molten steel in the ladle became periodic.

Fig. 13 shows the decrease in molten steel temperature until the completion of the 9th heat casting. The molten steel temperature is the average of all mesh temperatures in the molten steel section. Compared with the conventional lining containing carbon, the carbon-free lining in the steel bath suppressed the temperature drop by 4.7 ℃

5. Practical Application of Al_2O_3–MgO Castable Refractory for Teeming Ladle in EAF Steel Mills

Since several practical application examples of unburnt Al_2O_3–MgO brick, ALTIMA, for teeming ladle in EAF steel mill are already reported[2, 10, 15], application examples of alumina-magnesia castable refractory with precast

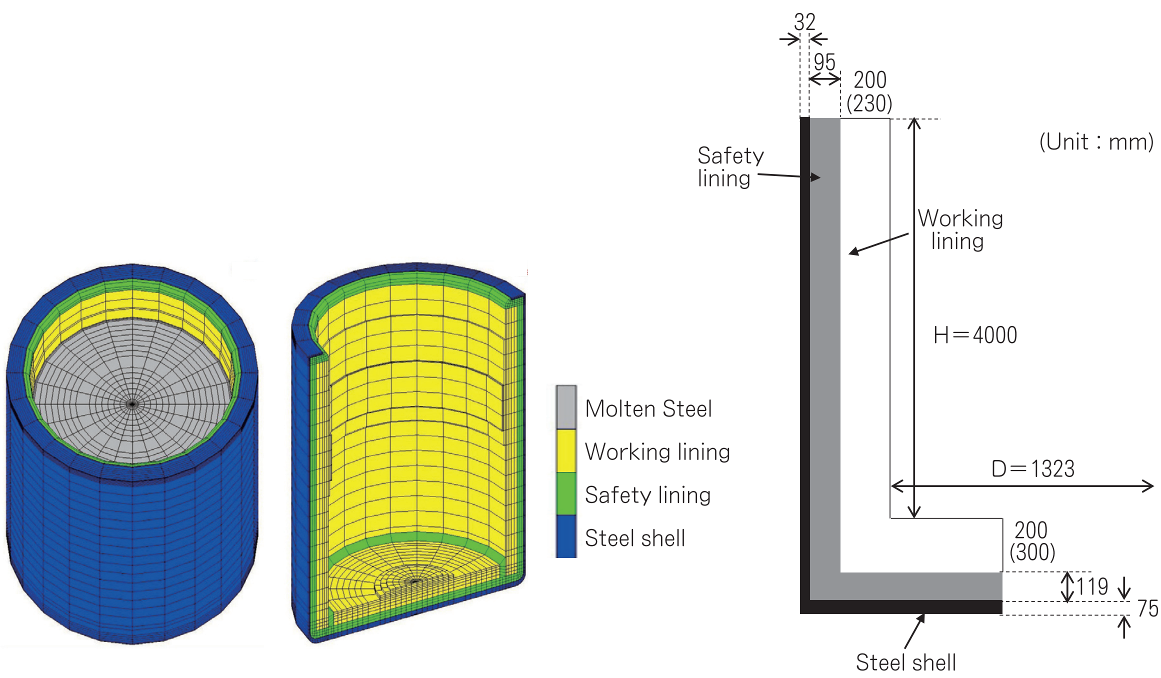

Fig. 11 3D-model of teeming ladle configuration for heat transfer analysis.

Table 3　Physical properties of work lining refractories for heat transfer calculation

Material		Al_2O_3-MgO-C (C=10%)	Al_2O_3-MgO
Bulk density / kg/dm^3		3.24	3.40
Thermal conductivity / $W{\cdot}m^{-1}{\cdot}K^{-1}$	RT 500℃ 1000℃	16.3 12.7 -	5.8 2.9 2.5
Specific heat / $kJ{\cdot}kg^{-1}{\cdot}K^{-1}$	RT 500℃ 1000℃ 1600℃	0.85 1.25 1.38 1.44	0.84 1.20 1.33 1.38

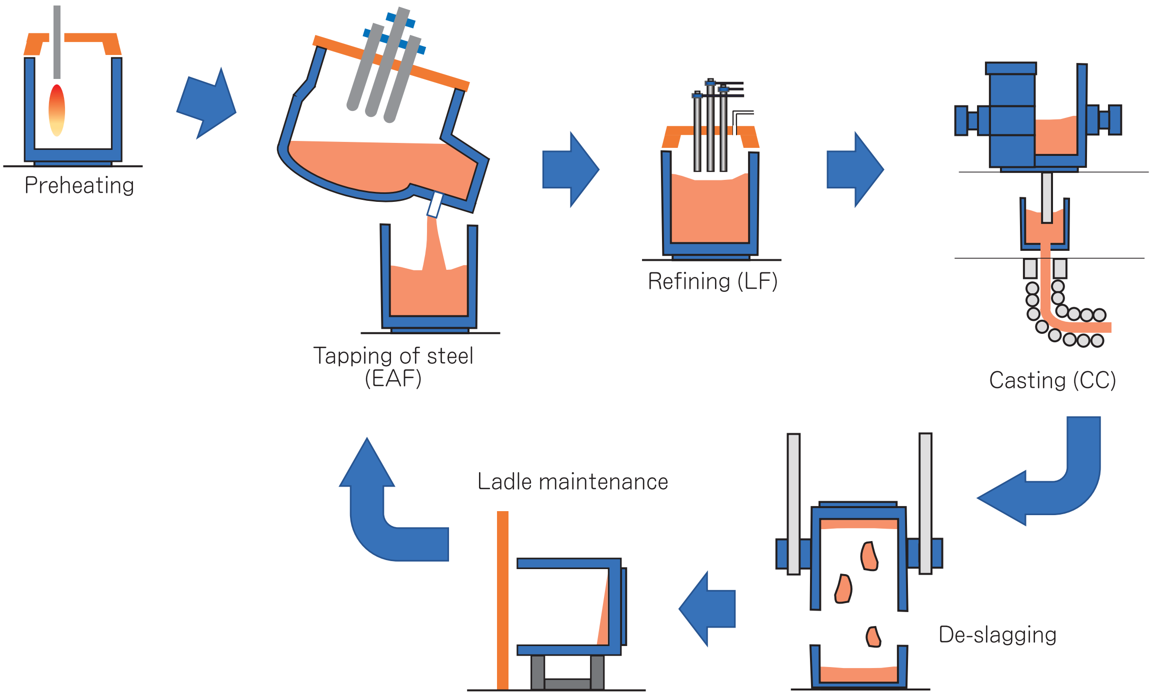

Fig.12　Schematic illustrations of teeming ladle operation cycle in EAF-steel mills.

Table 4　Teeming ladle operation cycle time schedule for heat transfer calculation

Process	EAF	⇒	LF		⇒	CC			⇒	Maintenance	⇒	(EAF)	Total
	Tapping		Holding	Refining		Killing	Casting	Deslagging					
Time / min	3	1	3	30	1	20	45	1	5	20	5		134

block or on-site relining for teeming ladle in EAF steel mill is introduced in this section.

5. 1　Impact zone precast block

Since the service life of teeming ladle refractories is occasionally regulated by severe damage of the impact zone in the ladle bottom, precast block is applied to the impact zone in many cases. Typical chemical and physical properties of impact zone precast block are summarized in Table 5. The maximum outside diameter of precast block products, which are provided by our company for teeming ladles used in integrated steel works or EAF steel mills, is 1500×1000 mm. They weigh over 1 ton. In the 250-300 ton capacity teeming ladles used in integrated steel works, 10-20 % of the teeming ladle bottom area is occupied by impact zone precast blocks. In the 80-120 ton capacity teeming ladles used in EAF steel mills, 20-40 %

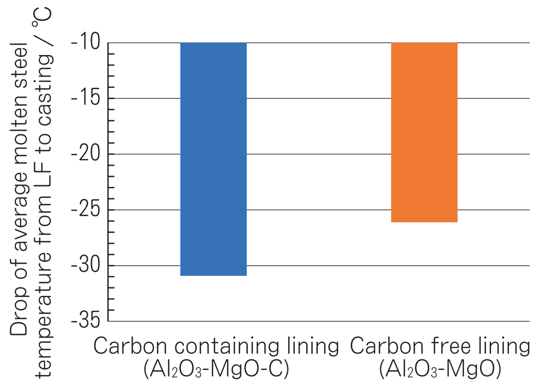

Fig. 13 Calculation result showing effect of teeming ladle relined refractory on average molten steel temperature drop from LF treatment to casting after 9 heats of operation.

of the teeming ladle bottom area is occupied by impact zone precast block because of smaller bottom area.

5. 2 Precast block relining for whole teeming ladle bottom

In overseas, not a few users have adopted large "floor blocks" that occupy more than 90 % of the ladle bottom in a few pieces. The overall appearance of precast blocks applied to a 300 ton teeming ladle in Port Kembla steel work, BlueScope Steel Limited, is shown in Fig. 14 along with surface appearance of teeming ladle bottom assembled with floor blocks. This is typical example of "floor block". These precast block products are fabricated in Shinagawa Refractories Australasia Pty. Ltd. (SRA) using SSC-AM372, chemical and physical properties shown in Table 5. For convenient purposes for transportation and relining or assembling work onto teeming ladle bottom, two pieces of precast block, each weighing 4.5 tons or 1.6 tons, are fabricated in the refractory plant and assembled on site. The diameter of the assembled "floor block" is roughly 3 meters. The thickness of the impact zone precast block was increased by roughly 100 mm to compensate for the severer damage sustained in the impact zone. Spaces between the teeming ladle wall and assembled floor block are relined with alumina-spinel castable refractory, SIRACRETE92SP, chemical and physical properties shown in Table 6. Due to its satisfactory workability and durability, alumina-spinel castable refractory has been stably applied. Horizontal deployment of "floor block" application for teeming ladle in domestic and overseas steel works is anticipated.

5. 3 Monolithic refractory relining for small capacity teeming ladle in EAF steel mill

In this sub-section, an example of monolithic refractory relining for teeming ladles with a smaller than 20 ton capacity is introduced. In this example, in accordance with technical suggestions and advices provided by our

Table 5 Chemical and physical properties of impact zone precast blocks

Code		SSC-AM239	SSC-AM372	SSC-AM640
Material		Al_2O_3-MgO	Al_2O_3-MgO	Al_2O_3-MgO
Chemical composition / %	Al_2O_3	92	92	93
	MgO	5	5	5
Permanent linear change / %	110℃×24h	-0.04	-0.03	-0.04
	1000℃×3h	-0.01	-0.03	-0.09
	1500℃×3h	0.95	0.53	1.01
Modulus of Rupture / MPa	110℃×24h	8.1	8.3	24.8
	1000℃×3h	13.6	15.5	32.4
	1500℃×3h	18.5	24.3	41.2
Cold crushing strength / MPa	110℃×24h	32.4	35.2	120.3
	1000℃×3h	61.4	68.2	144.1
	1500℃×3h	76.0	85.2	193.2
Apparent porosity / %	110℃×24h	12.3	12.9	7.3
	1000℃×3h	14.5	15.4	9.9
	1500℃×3h	18.2	19.5	15.4
Bulk density / g・cm^{-3}	110℃×24h	3.22	3.19	3.35
	1000℃×3h	3.20	3.14	3.32
	1500℃×3h	3.00	2.95	3.15
Application		Regular	Regular (for BlueScope)	High density

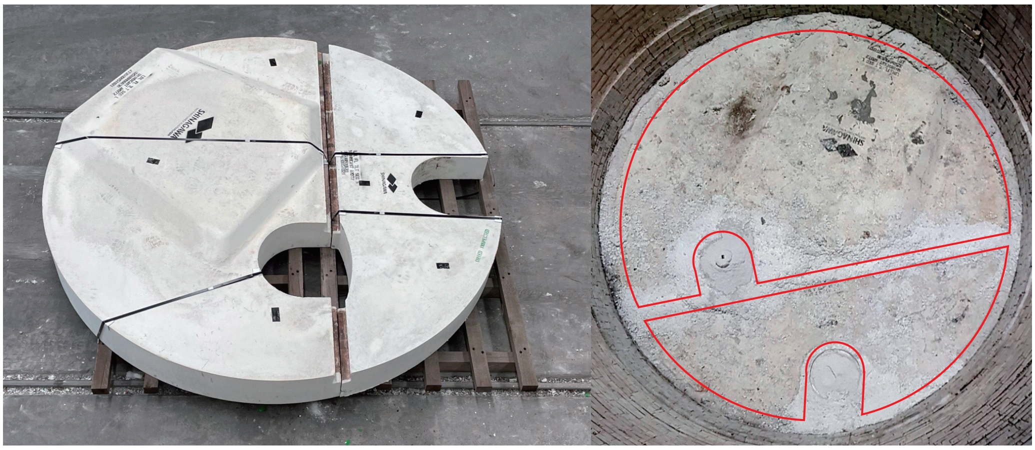

Fig.14　Exterior appearance of two-piece precast blocks applied for 300-ton capacity teeming ladle in BlueScope Port Kembla.

comapny, castable refractory relining on the teeming ladle and optimized drying and preheating for relined castable body are organized while utilizing existing facilities as much as possible so as to minimize investment cost for monolithic refractory relining. As a result, satisfactory performance was obtained with marked reduction of refractory unit consumption.

SSC-AM650 and SSC-AM411SY2 were selected from the SSC series of castable refractory products and applied to the ladle wall steel bath and ladle bottom, respectively. The typical chemical and physical properties of these two castable refractory products are summarized in Table 7. The SSC series is a casting mix that has been optimally designed to enable the relining operation with a small amount of water added using a mortar mixer of about 200 kg batch, which is available at any ladle relining shop, for example, as shown in the photo in Fig. 15(a). In an actual on-site ladle relining shop, the work was completed within the prescribed time without any problems.

Drying is necessary after the relining of unshaped refractories is completed. In integrated steel works with blast furnaces and converter furnaces, there is a plentiful supply of byproduct gas in the plant, and dedicated heat-up facilities are installed separately for drying the ladle after completion of relining work and for preheating operating ladles before the steel tapping. Therefore, well managed stepwise heating is possible. In the steel mill, however, it was difficult to use the preheating burner for drying for a long time since they equip the burner only for preheating purpose. The preheating pattern applied in the EAF mill, in comparison with the pattern in an integrated steel mill, is shown in Fig. 16. An electric hot air blower was used for the initial heat-up stage of the drying schedule, followed by a two-step heating that switched to the gas burner. After that, the ladle was able to be applied to the operation without any problem.

A molten steel ladle with the monolithic work lining described above was applied to an actual operation. The average service life of the conventional lining was about 20 heats, while that of this lining was 24 heats, which was

Table 6　Chemical and physical properties of SHIRACRETE92SP

Code		SHIRACRETE92SP
Material		Al_2O_3-MgO
Chemical composition / %	Al_2O_3 MgO	92 5.8
Permanent linear change / %	110℃×24h 1000℃×5h 1500℃×5h	-0.1 — 0.0 -0.3 — -0.1 -0.2 — +0.2
Modulus of Rupture / MPa	110℃×24h 1000℃×5h 1500℃×5h	9 — 13 11 — 17 >20
Cold crushing strength / MPa	110℃×24h 1000℃×5h 1500℃×5h	25 — 50 45 — 70 >80
Bulk density / $g \cdot cm^{-3}$	110℃×24h 1000℃×5h 1500℃×5h	2.93 — 3.03 2.91 — 3.01 2.88 — 2.98
Net quantity of dry material required for placement / kg/m^3		2960
Additional amount of water / %		4.0—5.0
Application		Ladle bottom around precast block

a good result. After that, only the infiltrated layer on the thick working area and the thin layer were demolished and replaced with a new layer and the ladle could be used for one more campaign, i.e., 48 heats. Since the amount of refractory topping off was about half of the initial amount of refractory relining, a reduction of about 37 % in the refractory unit consumption was achieved, which also led to a reduction in the amount of industrial waste.

6. Conclusions

It is prospected that, in accordance with progress of environmental and ecological activities for achieving carbon neutralization by 2050, the steel production ratio of the EAF has been increased along with increase of intensive secondary refining at EAF steel mills so as to guarantee steel quality. With such prospect, carbon free refractory relining of teeming ladle steel bath, in other words, application of Al_2O_3-MgO refractory materials with superior durability for the teeming ladle was introduced. The refractory materials can be selected from the ALTIMA unburnt Al_2O_3-MgO bricks, Al_2O_3-MgO castable mixes for on-site casting, and precast blocks of

Table 7 Chemical and physical properties of refractories applied to small capacity teeming ladle

Code		CST-AL-547	SSC-AM650	SSC-AM411
Material		Al_2O_3-MgO	Al_2O_3-MgO	Al_2O_3-MgO
Chemical composition / %	Al_2O_3	90	91	91
	MgO	7	7	7
Permanent linear change / %	110℃×24h	0.00	-0.03	-0.03
	1000℃×3h	0.00	-0.07	-0.03
	1500℃×3h	2.20	1.72	2.50
Modulus of Rupture / MPa	110℃×24h	7.6	5.7	12.0
	1000℃×3h	6.6	9.2	15.2
	1500℃×3h	21.1	29.4	30.5
Cold crushing strength / MPa	110℃×24h	32.5	23.6	52.3
	1000℃×3h	22.1	34.1	70.1
	1500℃×3h	74.2	91.3	92.7
Bulk density / $g \cdot cm^{-3}$	110℃×24h	3.08	3.03	3.19
	1000℃×3h	3.06	2.99	3.14
	1500℃×3h	2.87	2.85	2.78
Top grain size / mm		25	5	5
Additional amount of water / %		4.5−5.5	6.0−7.0	5.0−6.0
Application		Conventional	Metal-line	Bottom

(a) Mortar mixer for versatile application (b) Vortex mixer for large scale monolithic installation.

Fig.15 Examples of mixer for monolithic refractory installation.

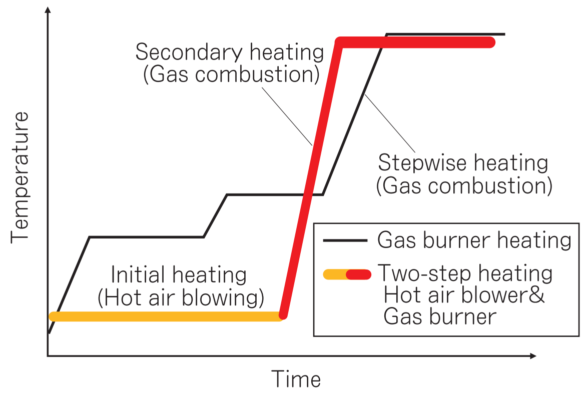

Fig. 16 Comparison of heating pattern for relined teeming ladle castable refractory.

Al_2O_3–MgO castables. The optimal combination of these materials can be used in severer environments than ever before. In accordance with operational conditions, Al_2O_3–MgO refractory relining on the teeming ladle is applicable with variety of configurations. Following three benefits are expected by relining carbon free refractory with low thermal conductivity on teeming ladle metal line.

1) Suppression of heat loss from teeming ladle steel shell, resulting in reduction of CO_2 gas emission
2) Prevention of molten steel contamination by C component in relined refractories
3) Reduction of unit consumption of teeming ladle refractories by partial additional relining repair on damaged teeming ladle refractory, resulting in reduction of waste disposal

In addition to application of ALTIMA for teeming ladle which has been introduced in many EAF steel mills, several examples of castable refractory and/or precast block application to the teeming ladle were introduced in this article.

Development of refractory materials have been conducted with the main purpose of providing refractory products which contribute to stable operation at a variety of furnaces or vessels in high temperature industries with low refractory cost. In addition to the above, development work on environment friendly refractory materials which will contribute to improvement of energy efficiency and/or reduction of waste disposal at users' site will be expanded.

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