Trends of Steelmaking Refractories*

By Yoichi NARUSE**

I. Introduction

I would like to express my deep gratitude for the honor bestowed on me by the Iron and Steel Institute of Japan with the award of the "Asada Prize". My thanks go to all the gentlemen involved in steelmaking without whose assistance I would never have received the prize. Requested a technical presentation of refractories as a supporting technology in iron and steelmaking at the 106th ISIJ Meeting, I chose the subject "Trends of Steelmaking Refractories", relying on my long experience in the area of the manufacturing and development of refractories for iron and steelmaking. I doubt my ability to satisfy you talking about refractories, the "everlasting problem" of the steelmaking industry, which must incessantly adjust to the demands of rapidly progressing steelmaking technologies. I would be pleased, however, if I could enable you to have a general view of the activities being carried out in the refractory industry.

Japanese industries have been making desperate efforts to overcome the first and the second oil crises which had a tremendous impact on them and brought about a sluggish market. Although the ways of coping with these crises are different depending on the type of industries, manufacturers, in general, place much more stress on quality rather than on production quantity and make all possible efforts to reduce production costs. During the period of high growth of Japanese economy, scale-up of production facilities and increase of productivity were the main objectives of endeavor. The targets now have altogether changed in nature and we may say that we are presently in "the second turnabout age". It will be necessary to continue making efforts to cut costs by saving energy, natural resources and labor, and by improving yields and simplifying processes. This certainly applies to the refractory industry, as well. The major requirements for us of our customers in the steel industry consists in the cost reduction of refractories. A dramatic reduction of refractory consumption per steel has been achieved in the iron and steelmaking industry. This is mainly attributed to the improvement in operational techniques, specifically in various operation controls, in process control technology, and in the technology of hot gunning repair, and also as the result of endeavors in the process reduction realized by the development of

continuous casting process which is highly appreciated.

I am firmly convinced that the quality improvement of refractories also played an important role in achieving this reduction of refractory consumptions. The fact, however, that quality improvement has not necessarily meant reduction in the refractory cost per steel, indicates that it should be accompanied by more initiatives for saving energy, resources and labor.

As for the turnabout "from production in bulk to quality", we are proceeding, like it or not, toward a "Multi-product Less-production" system, since the customers' requirements in quality always tend to vary and diversify.

Since an improvement in quality means an increase in added value, we cannot spare ourselves a single day in achieving sophisticated technologies and developing state of the art products, which are the basic philosophy of management.

On the background of the iron and steel industry whose technology is developing exceedingly rapidly with diversified needs for refractories, I would be pleased to make a technical presentation of "Development of Refractories for Steelmaking and Continuous Casting Process, and Sliding Gate Nozzles" for which I had the honor to receive the "Asada Prize", describing the present status and the future development of individual refractories used for specific process units.

II. Pig Iron Pre-treatment Process and Refractories in Torpedo Ladle

Since 1973, the desulphurization process in torpedo ladle has become widely used. At the sametime, the processes aiming at desiliconization and dephosphorization have increasingly been applied. The agents are different depending on steel makers, but in general mill-scale is used for desiliconization and limestone or soda-ash for dephosphorization and desulphurization with some accelerating additives.¹⁾ The history of refractories used for lining of the ladle are schematically shown in Fig. 1.

$\text{Al}_2\text{O}_3\text{-SiO-C}$ bricks have been widely employed due to the increasingly severer operating conditions of dephosphorization incorporated with desiliconization.²⁾ Typical properties of the lining bricks are shown in Table 1. The main feature of these bricks is good corrosion and spalling resistance by virtue of the combined effect of flake graphite and SiC; since

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the effect of “flake graphite” is resistance to spalling and corrosion, and that of “SiC” is resistance to oxidation as expressed in the following formula:

whereby, SiO₂ produces glass zone on the brick surface, which in turn, reacts with slag to form a coating layer that protects the brick from further oxidation. However, adjustments of the amounts of addition and grain sizes of the raw materials must be exact not to allow the reaction of the above formula to occur so excessively as to form densified structures in matrix, resulting in peeling of brick.

In Photo. 1, a transient conversion process of Al₂O₃-SiC-C brick near the hot face is shown. Oxidation of a grain from the periphery can be observed in the same photo.

A lance to inject pre-treatment agents is studied in structure and lining materials (mainly castable). The main reason of this lance damage is due to a crack penetration caused by faulty matching of the metal

lance pipe and the protecting lining refractories (pipe vibration and difference of thermal expansion between pipe and refractories).³⁾ This indicates the importance that it be considered from two different viewpoints. The life of the castable used for lining has been extended by the pre-casting of a clay bond castable which reduces the amount of low melting-point material. However, more durable materials

Photo. 1. SiC grain whose periphery has been altered to glass material.

Fig. 1. Typical lining profile for pig iron pre-treatment in torpedo ladle.

Table 1. Typical properties of refractories for pig iron pre-treatment in torpedo ladle.

Material	Super-duty fireclay brick (burned)	High alumina brick (burned)	Al ₂ O ₃ -SiC-C brick (unburned)	MgO-C brick (unburned)	Castable for mouth [max. working temp. 1 600 °C (2 910 °F)]
Apparent S. G.	2.69	3.20	3.13	2.94	2.82
Bulk density	2.35	2.64	2.78	2.83	2.20
Apparent porosity (%)	12.5	17.5	11.2	3.7	22.0
Cold crushing strength (kg/cm ²)	900	1 050	530	370	670
Modulus of rupture (kg/cm ²)					
{ at room temp.	220	180	230	180	150
{ at 1 400 °C (2 550 °F)	30	60	52	40	20
Thermal expansion (%)					
at 1 000 °C (1 830 °F)	0.55	0.52	0.48	1.00	0.53
Chemical composition (%)					
{ SiO ₂	53	22	7	—	32
{ Al ₂ O ₃	42	75	59	—	60
{ SiC	—	—	18	MgO 78	—
{ C	—	—	10	20	—
Remarks	Lining in general	Slag-line & mouth; corrosion & spalling resistance	SiC-C added to high alumina material; corrosion & spalling resistance	C added to magnesia; corrosion resistance	Properties of castable measured after 1 500°C (2 730 °F) × 3 h

are still demanded.

The present problems and the future trend of refractories for pre-treatment of pig iron will be discussed in the following.

1. $\text{Al}_2\text{O}_3\text{-SiC-C}$ Brick

$\text{Al}_2\text{O}_3\text{-SiC-C}$ brick, which consists mainly of the refractories used for torpedo ladle for pig iron pre-treatment, involve some problems.

1. Zone Lining to Provide for an Increase in Pretreatment Ratio

- i) Slag line: (corrosion resistance), spalling resistance, CO gas resistance
- ii) Metal zone: corrosion resistance (CO gas resistance)
- iii) Impact area: (shock load resistance), corrosion resistance, CO gas resistance
- iv) Roof: (oxidation resistance), corrosion resistance

Note:

The properties in parentheses are strongly required subjects. In conjunction with the trend of the increased application of refining process and the diversified purposes of processing (desulphurization, desilicization and dephosphorization) and methods, it has become a normal practice to create products most appropriate in terms of corrosion loss balance to minimize cost) by selecting the most proper material grades depending on the portions of the ladle to be used. A point that has recently attracted attention specially is a problem of SiC oxidation occurring inside of bricks. Oxidation occurring on the surface of brick in direct contact with molten iron produces a markedly useful viscous glassy phase which provides oxidation preventive functioning. Whereas, oxidation taking place inside of the brick will cause the destruction of brick structure, resulting in shortening of the service life. Judging from the fact that SiC is selectively oxidized in the $\text{Al}_2\text{O}_3\text{-SiC-C}$ brick to give rise SiO_2 and carbon *in situ* of SiC, the chemical reaction shown in the following formula may occur in the inside of the brick.

In the future a way should be found to prevent oxidation by CO gas without damaging the feature of $\text{Al}_2\text{O}_3\text{-SiC-C}$ brick. In the case of $\text{Al}_2\text{O}_3\text{-SiC-C}$ brick used in the roof, the cold-face is more liable to structural failures due to oxidation of carbon bond than the hot face. Prevention of oxidation of the cold-face is not easy, because of the oxidation temperature of brick ranging below 1 000 °C (1 830 °F). The impact area indicates the desirable results by using burned $\text{Al}_2\text{O}_3\text{-SiC-C}$ brick with increased graphite content.

2. Higher Thermal Conductivity

$\text{Al}_2\text{O}_3\text{-SiC-C}$ brick have a thermal conductivity over four times that of conventional bricks (super-duty fireclay brick and high alumina brick) as shown in Table 1. When comparing calculated shell temperature of the ladle lining composed of steel shell (30 mm), fireclay brick (114 mm, $\lambda=0.9$), castable

(20 mm, $\lambda=0.67$) and wear lining (346 mm) with fireclay brick ($\lambda=1.37$) and $\text{Al}_2\text{O}_3\text{-SiC-C}$ brick ($\lambda=7.7$), we obtain 210 °C (410 °F) for the former and 293 °C (560 °F) for the latter, which means that the use of $\text{Al}_2\text{O}_3\text{-SiC-C}$ brick will raise the shell temperature by 80 °C, causing a drop in molten iron temperature (heat radiation: 2 909 Kcal/m²·h, 5 495 Kcal/m²·h). Improvement of thermal insulation can be considered a countermeasure, but this will bring about a slackened temperature gradient in the lining, which in turn will cause a larger corrosion of brick and a deeper penetration of metal into the joint, which problems should be solved in the future in view of construction stability (insulating brick is low in strength), *i.e.*, material and structure.

3. Improvement in Mortar

$\text{Al}_2\text{O}_3\text{-SiC-C}$ brick presented new difficulties: usage of conventional mortar for brick construction was impossible because of extremely low water absorption as a result of high pressure molding of the brick with mixture containing 10 to 25 % graphite by using phenol resin as a binder. A special mortar using resin as a binder, in which square grains are properly dispersed, has recently been developed and used in practically, but further improvements in workability are still required.

2. Countermeasures in Torpedo Ladle for Soda-ash Pretreatment

Soda flux (soda-ash) has been applied by several companies which succeeded in the industrialization of soda recovery techniques, since soda flux (soda-ash) can carry out at the same time both dephosphorization and desulphurization with excellent results.⁵⁾ It is well known that N_2O , a strong basic component, accelerates the corrosion of refractories because of its reaction which reduces slag viscosity by cutting the SiO_2 networks in the slag. Therefore, the lining of a torpedo ladle, in which a large amount of soda-ash was injected, was severely corroded as compared with a torpedo ladle in which CaO and CaC_2 were used. Containments of greater amounts of desilicized slag easily form $\text{FeO-Na}_2\text{O-SiO}_2$ slag, causing an increasingly stronger corrosion reaction.

No desirable results have been obtained from magnesia-chrome brick and MgO-CaO brick, because of the tendency to produce structural spalling by allowing slag penetration into the brick, while these bricks are excellent in corrosion resistivity. MgO-C brick are good in corrosion and spalling resistance, but their expansion is large and oxidation (decarburization) tend to occur more easily than $\text{Al}_2\text{O}_3\text{-SiC-C}$ brick. $\text{Al}_2\text{O}_3\text{-SiC-C}$ brick show the most stable results at the moment with a desirable oxidation resistance, though they are much inferior in corrosion resistance to MgO-C brick because of the formation of a low melting point liquid of $\text{Al}_2\text{O}_3\text{-SiO}_2\text{-Na}_2\text{O-FeO}$.⁶⁾ However, $\text{Al}_2\text{O}_3\text{-SiC-C}$ brick are now being modified by lowering the content of SiC and SiO_2 to overcome the slack of brick structure and a lower corrosion resistance by the oxidation of SiC. It has been normal practice to prolong the

service life of the lining of a torpedo ladle by periodically repairing severely damaged parts of the ladle, thereby taking the corrosion balance. Quite recently, however, an attempt was made to repair it at high temperature, in order to save energy and labor. In relation with this trial, inside observation instrument and special hot gunning machines for torpedo ladle have been developed, some of which have already been put to practical use.

III. Duplex Blowing and Refractories

Duplex blowing B.O.F. was practically employed in the early 1980's in an attempt to attain various objectives such as protection of sloppings and over oxidation of slag and their resulting effects of increase in metal yield, of uniformity of steel constituents and molten metal temperature, of increase in productivity, and of acceleration of dephosphorization and desulphurization. This method, at the moment, seems to have permanently been accepted in this industry, in different forms depending on the individual plants. When we look at the changes of bricks of tar-bonded dolomite-magnesia brick and burned dolomite-magnesia brick used for top-blowing B.O.F., and to increase the use of unburned Mg-C brick. Typical properties of brick for B.O.F. are given in Table 2.

In duplex blowing B.O.F., MgO-C brick are mostly employed for the bottom tuyeres and around them, as they are severely worn. Figure 2 shows a model of the wear mechanism around the tuyere of the duplex blowing B.O.F. While the tuyere bricks are protected at the hot face by the cooling effect of the cooling gas and the formation of mashroom-like accretions, the conditions which surround these brick become very severe because of the mechanical impact of falling off molten steel after being blown up, called "back-attack", the high temperature caused by the reaction ($C+O_2 \rightarrow CO_2$, $Fe+O \rightarrow FeO$) of the molten steel with the blown gas (O_2) near the tuyere, and the physical erosion and chemical corrosion taking place by a rapid stirring of the molten steel high in (O) content. The size of the brick tends to be larger to provide a stabler structure. This requires high

quality materials, designing and the technical know-how to manufacture high-grade large brick around tuyere.

The upper bath and the cone of the vessel, which were not much worn were recently worn depending on operation. The type of brick used for this purpose has naturally been changed according to the change in the blowing method. The correlation between the graphite content, spalling and corrosion resistance of MgO-C brick is shown in Fig. 3. Both resistances are improved with the increase in graphite content, but, if the content exceeds 35 wt%, the molding performance becomes worse and the abrasion resistance to molten steel decreases. A graphite content of around 20 % is in general the most practical. On the other hand, the performance of MgO-C bricks depend on the kind of flake graphite and MgO clinker as raw materials, or special additives.

Figure 4 shows the relation between the purity of graphite and corrosion resistance in 20 % graphite MgO-C brick. Graphite of higher purity gives better corrosion resistance, but the cost of 90, 95 and 99 % graphites are 1:1.5:2 in ratio. They, therefore, must be chosen properly to meet the working

- 1: High cooling effect by cooling gas
- 2: Back attack
- 3: Abrasion by molten steel stream rich in [O]
- 4: High temperature by firing around tuyere
- 5: Mechanical stress

Fig. 2. Factors of wear around tuyere of duplex blowing B.O.F. Condition: 1 700 °C (3 090 °F)

Spalling test condition:

Dip in hot metal at 1 600 °C (2 910 °F) for 90 sec
—Water cooling 30 sec—Air cooling 30 min × 5 times,

Corrosion test condition:

1 700 °C (3 090 °F), $CaO/SiO_2 = 3.3$,
T.Fe=13.3 % in slag

Fig. 3. Effect of graphite to spalling and corrosion resistance.

Table 2. Typical properties of Mg-CaO-C brick and MgO-C brick.

Materials	MgO-CaO-C brick	MgO-C brick
Apparent specific gravity	2.98	2.97
Bulk density	2.86	2.85
Apparent porosity (%)	3.8	4.0
Cold crushing strength (kg/cm ²)	344	355
Modulus of rupture (kg/cm ²)		
{ at room temp.	147	157
{ at 1 400 °C (2 550 °F)	55	57
Weight decrease rate after vacuum heating (%)	12.0	16.4
1 500 °C (2 730 °F) × 1 h		
Chemical composition (%)		
{ CaO	15.7	1.0
{ MgO	63.6	78.6
{ C	18.8	18.8

Fig. 4. Relation of graphite purity to corrosion resistance.

condition of each portion taking the cost into consideration.

Figures 5 and 6 show the relationship between the aluminum powder content in MgO-C brick and its strength and permanent linear change. As the addition of aluminum increases, the strength increases as well, but due consideration should be paid to the structure of the brick work, because permanent linear change increases at the same time. As mentioned before, high performance refractories are required with the progress of duplex blowing in B.O.F., having the following problems.

(1) It is assumed that wear in MgO-C bricks advances by repetition of the following processes:

- 1) Formation of a decarburized layer on the hot face;
- 2) Invasion of slag into the decarburized layer;
- 3) Reaction of the slag with MgO; and
- 4) Dissolution of the deformed MgO.

Photograph 2 shows a typical deformed hot face. For the improvement of these properties, it is necessary to upgrade the graphite purity, and to select MgO clinker and/or other additives. However, the most important point is to get the high density of the brick itself. For improving the brick qualities, it is necessary to adopt the most modern equipment. A high pressure molding plays a determinant role.

(2) MgO-CaO-C brick, to which attention has recently been paid, show excellent resistance to corrosion, especially when employed in the bath and bottom where contact with high temperature molten steel by forming high refractory slag coating through dolomite grain with MgO-C reaction controlled. However, it should be noted that the corrosion resistance of this brick can be lowered, depending on the concentration of total Fe in the slag.^{7,8)}

(3) Expectations have been placed on the characteristics of MgO-CaO-C brick used for slag-minimum operation, because the employment of MgO-C brick in such operation, in spite of permitting reduction in corrosion loss by slag, reduces favorably slag coating and accelerates carbon bond oxidation in gaseous phase, reaction of MgO+C and abrasion by molten steel.

(4) Wear of lining brick at the tuyeres and around the tuyeres is one of the big problems in duplex blowing B.O.F. that produce stainless steel. During

Fig. 5. Effect of aluminum addition on hot modulus of rupture.

Fig. 6. Permanent linear change in aluminum contain MgO-C brick.

Photo. 2. Corrosion mechanism of MgO-C brick.

blowing of stainless steel, CaO/SiO₂ ratio of slag changes greatly and the lining bricks may wear at 10 to 20 mm/heats because the molten steel temperature increases extremely in the blowing process to improve the yield of chromium. Various kinds of brick for lining such as the MgO-C, MgO-CaO-C, and MgO-Cr₂O₃, have been tried, but to date no epochmaking result has been reported, leaving this as a major problem to solve.

As the development of duplex blowing process, the lining bricks has been improved to be high in performance and properties starting from employment of MgO-C bricks in furnace proper, so as to meet the needs as a whole. There are, however, still unsolved points such as problems in stainless steel furnaces.

IV. Secondary Steelmaking and Refractories

For secondary steelmaking process, there are many operating processes and conditions such as vacuum

refining, ladle refining, etc. Refractories are therefore used in unique combinations of various bricks to meet such diversified conditioned. In any operations, however, the refractories are used under the following severe conditions:

- 1) High temperature of the steel and long holding time;
- 2) Wide variation of slag composition and fluidity of molten steel;
- 3) Large abrasion by stirring of molten steel;
- 4) Many cases of vacuum treatment; and
- 5) Large thermal changes.

Steelmakers, however, are rapidly introducing secondary steelmaking process in order to cope with the requirements in wide scope such as steel quality improvement, higher productivity, and saving of resources and labor. The refractories used for the “LF”, “ASEA-SKF”, “VAD” and “RH” processes are briefly discussed in this chapter.

1. LF, ASEA-SKF, VAD Process and Refractories

These are called ladle-refining processes which functionally provide heating, stirring, slag refining and degassing. Although the lining profile differs slightly depending on steelmakers, they are basically similar. (Fig. 7)

Table 3 shows typical properties of lining bricks for LF ladle.

1. Brick for Slag-line

MgO-Cr₂O₃ or MgO-CaO bricks were formerly used for this area, but because of severe slag corrosion and peeling off caused by drastic temperature changes which take place in intermittent operations, the brick have presently been replaced with MgO-C brick with successful performance.^{10,11)} They differ slightly from

the MgO-C brick for B.O.F. Figures 8 to 11 show comparison of the effects of various metal additions on the properties of MgO-C bricks for slag-line. Addition of metals in the bricks improves their properties differently, depending on the kind of metals added. Careful attention should be paid to use the suitable brick depending even on the different positions of the slag line which is classified into bubbling side and slag off side.

2. Refractories for Wall, Bottom and Impact Area

For general wall, high alumina brick are widely used to provide stable properties against a long period of contact with high temperature steel, and to help making clean steel. For bottom, zircon brick with high volume stability, are widely used to prevent molten steel penetration into the brick joint. For impact areas, which involve the most difficult questions, MgO-C, Al₂O₃-C bricks, and castable pre-cast blocks are used with a certain success.^{10,12,13)} Table 4 shows the typical properties of bricks for wall, bottom, and tuyere.

2. Refractories for RH Vessels

Refractories for important parts, such as the lower part of vessel and snorkel, need to have good spalling and abrasion resistance, volume stability and corrosion resistance at vacuum high temperature. Damage of the lower vessel and the snorkel is mainly worn by the thermal spalling; but wear by peeling and abrasion seems to advance with destruction and tight-

Fig. 7. Example of lining profile for LF ladle.

Table 3. Typical properties of lining brick for LF ladle.

Material	Magnesia-carbon brick, unburned, CRD-HMR20C	Magnesia-carbon brick, unburned, CRD-AMR20CX
Apparent S. G.	2.94	2.94
Bulk density	2.83	2.84
Apparent porosity (%)	3.7	3.4
Cold crushing strength (kg/cm ²)	363	370
Hot modulus of rupture (kg/cm ²) at 1 400 °C (2 550 °F)	127	162
Thermal expansion (%) at 1 000 °C (1 830 °F)	1.66	1.71
Permanent linear change (%) at 1 000 °C (1 830 °F) × 2 h	0.38	0.53
Chemical composition (%)		
{ MgO	76.1	75.4
{ F. C	18.1	18.2
Features	Typical metal added MgO-C brick, excellent in oxidation and abrasion resistance	MgO-C brick with addition of a couple of metals, excellent in oxidation resistance (especially in liquid) high hot strength, good in resistance to joint corrosion because of its excellent adhesive each other
Application	Impact area	Slag line

ness of structure resulting from slag penetration. Figure 12 shows the system of RH process.

As more RH treatment and functions (deoxidation, decarbonization, composition adjustment, etc.) are required for latest RH vessels, the lining refractories, especially those in the lower vessel and snorkel, are used on severer operating conditions.¹⁴⁾ In order to meet these needs, direct bonded magnesia-chrome brick are being replaced to semi-rebonded magnesia-

chrome brick used with electro-fused magnesia-chrome clinker,^{15,16)} and application of extrahigh temperature burned magnesia-chrome brick is being studied in some works. Recently excellent functions of RH process have attracted attention specially. The extra-high temperature burned magnesia-chrome brick which are excellent in corrosion and abrasion resistance, will be applied as a main lining material in near future. For higher efficiency in the operation of RH, the hot repairing technology will become

Fig. 8. Comparison of oxidation depending on the amount of metal addition.

Fig. 9. Comparison of corrosion resistance depending on metal addition.

Fig. 10. Comparison of hot strength depending on metal addition.

Fig. 11. Comparison of thermal conductivity depending on carbon content.

Table 4. Typical properties of bricks for wall, bottom and tuyere.

Material	High alumina, unburned ALU-DL6	High alumina, unburned ALU-5CF	Zircon, burned STZ-S3	Zircon, burned STZ-PZS	High alumina, unburned KVR-B810R	
Apparent S. G.	3.66	3.54	4.34	4.52	3.86	
Bulk density	3.15	2.97	3.59	3.78	3.20	
Apparent porosity (%)	14.1	16.1	17.2	16.4	12.2	
Cold crushing strength (kg/cm ²)	704	738	1 342	1 110	546	
Thermal expansion (%) at 1 000 °C (1 830 °F)	1.86	1.50	0.76	0.68	1.79	
Permanent linear change (%) at 1 000 °C (1 830 °F) ×2 h	+1.58	+1.66	−0.03	−0.03	+0.68	
Chemical composi- tion (%)	SiO ₂	6.7	9.3	33.9	34.1	—
	Al ₂ O ₃	89.9	85.4	6.4	—	95.1
	CaO	—	—	—	—	1.2
	ZrO ₂	—	—	58.6	63.8	—
Features	Excellent in structural spalling resistance and joint corrosion resistance by proper arrangement of natural and synthetic alumina	Standard unburned high alumina brick mainly using high purity natural alumina	Good volume-stability, less slag penetration, excellent in structural spalling resistance	Densified by adoption of secondary grain, zircon brick with excellent corrosion and spalling resistance	Castable precast product with high strength and density, excellent in corrosion and abrasion resistance	
Application	Wall free board	Wall free board	Bottom	Bottom	Tuyere	

more important.¹⁷⁾ Table 5 gives typical properties of RH refractories.

V. Continuous Casting Process and Refractories

The continuous casting process is an equipment and a technology of paramount importance in the rationalization of the steel industry such as the high yield of steel products and the saving of energy, labor and also resources. The progress of its technical development are remarkable. Efforts to increase kinds of casting steels and to realize sequential continuous casting process have been highly evaluated. The refractories used for continuous casting processes are roughly classified into refractories for ladles, sliding gate nozzles, shroud submerged nozzles, and tundish refractories.

Fig. 12. System of RH process.

1. Refractories for Ladles

The ladle, which was once only a molten steel container, has been changed to such a considerable extent that gas bubbling and processing by RH or DH can by no means be omitted from the continuous casting process at this time, and severer conditions have been given to the ladle refractories. Pyrophyllite brick had been used on account of their reasonable price and excellent properties. However, their big corrosion by molten steel under severe operating conditions has made pyrophyllite brick unavailable in this usage and its replacement with "zircon", "high alumina", or "basic" bricks is now under way.

The zircon brick tend to be more densified structure without spoiling the resistance to spalling.¹⁸⁾ High-alumina brick are not in use except for secondary refinings because of their poor resistance to slag penetration and to structural spalling; because of their poor flexibility as structure, because of the wear at joint, and because of molten steel penetration. "Basic brick", which have come a long way since they were tested as ladle bricks, have not yet been employed, practically owing to their instable properties in resistance to structural spalling and to adhesion of slags and metals. However, from the aspect of the demands for clean steels, this type of brick is again studied for practical use with equipment for thermal insulation and basic monolithic refractories are also tried for use.¹⁹⁾

2. Refractories for Sliding Gate Nozzles (Refractories for SN)

The SN system, which provides flow controls of molten steel from the outside of the ladle without any interference by the bubbling, the flux injection, and which assures a long period of holding time, is an indispensable technology supporting the present ladle

Table 5. Typical properties of RH refractories.

Material	Mg-Cr semi rebonded		Mg-Cr direct bonded		Magnesia rebonded	
	KRD-SME11	KRD-SME12	KRD-DH36	KRD-TH	KRD-PE	
Apparent S. G.	3.78	3.68	3.68	3.61	3.55	
Bulk density	3.25	3.09	3.08	2.98	3.00	
Apparent porosity (%)	14.0	16.1	16.2	17.5	15.3	
Cold crushing strength (kg/cm ²)	800	929	—	660	1 350	
Modulus of rupture (kg/cm ²)						
{at room temp.	100	123	65	70	200	
{at 1 480 °C	98	109	68	50	30	
Refractoriness under load (<i>T</i> ₂ , °C)	>1 700	>1 700	>1 650	>1 650	>1 650	
Chemical composition (%)	{SiO ₂	1.7	1.3	1.4	2.4	0.4
	{Al ₂ O ₃	11.0	6.7	7.9	6.2	—
	{Fe ₂ O ₃	10.8	5.0	4.6	2.9	—
	{Cr ₂ O ₃	24.3	11.3	13.3	7.0	—
	{CaO	0.7	0.8	0.8	1.0	—
	{MgO	55.1	74.6	71.5	80.2	98.4
Application	Lower vessel, side wall, bottom, snorkels, legs			Upper vessel	Electrode holes, alloy charging door	

refining and continuous casting process, and is installed in most of the ladles. Recently it has been displaying excellent effects on the flow control and automatic casting in the tundish.

1. Plate Brick

Plate bricks are exposed to considerably severe conditions, such as spalling caused by repeated contacts with high temperature molten steel, damages on hole edges by molten steel flowing to sliding surfaces. In using ceramic bonded plate brick impregnated with pitch, the smoking is a problem. Carbon bonded alumina plate brick, no smoke and with a longer service life, are rapidly replacing ceramic bonded bricks.^{20,21)} Specifically, carbon bonded brick to which raw material containing zirconia (low volume expansion due to a phase transformation from monoclinic to tetragonal form), ALZIR (ALZ), have achieved excellent performance.²²⁾ The SN plates containing zirconia are a sign of quick increase of their use.

Tables 6 and 7 show typical properties of the plate brick. The plate brick have a problem for casting extra-low-carbon steel with high oxygen (O) or sulphuric free-cutting steel. For these grades of steel, basic brick must be employed instead of alumina brick, not resistant enough to this environments. Various kinds of the SN plate will be required to mate with the grades of steel to be processed.

2. Upper Nozzle Brick

The upper nozzle brick, which need to have a multiple times longer service life of plate brick, is required to have corrosion resistance to molten steels and slags rather than spalling resistance because it is set in the nozzle seating block. As indicated in the table, resin bonded bricks have recently been favorably employed because of their high hot strength and of applicability for raw materials which range from fireclay to basic. Table 8 shows typical properties of upper nozzle brick.

One important problem for the upper nozzle brick,

besides service life, is the phenomenon of nozzle clogging in teeming Al or Ti-bearing steel. For solving this problem, a selection of brick material easy to be eroded by molten steel comes to mind as a countermeasure from material side, but this brick, with larger corrosion loss, will have a shorter service life. Therefore, a physical method to prevent the building up of deposits from molten steel by blowing inert gas from the inner surface of the upper nozzle, has been successfully developed and is widely applied for making the sequential continuous casting possible. (Fig. 13)

Table 6. Typical properties of ceramic bonded plate brick.

Material	HRD-SNA	HRD-SNU	HRD-SNE	BASN-103
Bulk density	3.15	3.05	2.90	3.02
Apparent porosity (%)	15.0	17.0	16.0	15.6
Cold crushing strength (kg/cm ²)	1 700	1 500	1 400	1 100
Modulus of rupture (kg/cm ²) at 1 400 °C (2 550 °F)	90	90	70	45
Thermal expansion (%) at 1 000 °C (1 830 °F)	1.10	0.95	0.90	1.29
Chemical composition (%)				
Al ₂ O ₃	95	92	87	MgO: 94
SiO ₂	3	5	11.5	ZrO ₂ : 4
Fixed carbon	2.5	2.5	2.5	2.5
Volatiles	2~3	2~3	2~3	2~3
Remarks	Plate for tundish	Ladle, CC and IC	Ladle, IC	Ladle for electric furnace, tundish TD

Table 7. Typical properties of carbon-bonded plate brick.

Material	CAN (CAT)		ALZ-N		
	CAN108	CAN112	ALZ204N	ALZ256N	ALZ309N
Bulk density	2.80 (2.85)	2.85 (2.90)	2.95	2.90	3.10
Apparent porosity (%)	9.0 (3.0)	8.0 (3.0)	8.0	8.0	7.0
Cold crushing strength (kg/cm ²)	1 500 (1 700)	1 700 (1 800)	1 500	1 600	1 500
Modulus of rupture (kg/cm ²) at 1 400 °C (2 550 °F)	120 (250)	140 (250)	150	160	180
Thermal expansion (%) at 1 400 °C (2 550 °F)	0.90	0.95	0.85	0.85	0.85
Chemical composition (%)	Al ₂ O ₃	72	74	69	73
	SiO ₂	8	6	3	3
	ZrO ₂	—	—	6	6
	C	11	11	11	10
Remarks	Original one of carbon-bonded brick, for general ladles	Higher corrosion resistance of CAN108, for general ladles	Lower thermal expansion of CAN108	Improvement of corrosion resistance of ALZ204, for big ladles	High density, low permeability, for big ladle and tundish

Fig. 13. Example of construction of upper nozzle brick for gas bubbling.

Table 8. Typical properties of upper nozzle brick.

Material	Burned brick		Unburned brick	
	HRD-SNA	ZRD-SNZ	RMC-A141	RMC-MS309
Bulk density	3.00	3.60	3.05	2.82
Apparent porosity (%)	19.5	17.0	7.0	10.0
Cold crushing strength (kg/cm ²)	1 400	1 300	1 400	1 200
Modulus of rupture { at room temp. at 1 400 °C (2 550 °F)	230 60	— —	210 90	220 190
Thermal expansion (%) at 1 400 °C (2 550 °F)	1.15	0.70	1.4	2.10
Chemical composition (%)	Al ₂ O ₃	—	93	15
	SiO ₂	31	—	MgO 78
	ZrO ₂	53	—	—
	C	—	4	4
Remarks	For general use	High alumina brick for kiln steel, limited use for one (1) charge	High corrosion resistance, used 10 to 15 charge for a large size ladle	High corrosion resistance, used 10 to 15 charge for a large size ladle

3. Lower Nozzle Brick

For the lower nozzle brick, pitch-impregnated burned bricks were used only for their excellent corrosion and spalling resistance, without any requirement of stable flow because of a shrouds set underneath this nozzle; however, now resin-bonded nonsmoke unburned brick are replacing the afore-said brick. In Table 9, typical properties of lower nozzle brick are given.

- These bricks have the following characteristics:
- 1) Better in corrosion resistance than burned brick;
 - 2) Easy to choose materials of high corrosion; resistance or spalling resistance to suit the working conditions;
 - 3) Little smoke produced; and
 - 4) Shape maintained precisely due to unburning to allow bricks to be easily set with plate brick.^{23,24)}

4. Nozzle Filling Material

In a ladle equipped with the SN device, generally upper nozzle hole is filled with some material to prevent molten steel entering into nozzle hole and solidifying therein during receiving the molten steel. As filling materials, steel chips or silica sand are generally utilized, but the former need oxygen blowing

for opening the hole and the latter will contaminate the molten steel. Recently, basic material have been developed as the filling material, but grain size distribution and sintering ability should be taken into consideration. (Table 10)

3. Shroud (or Long Nozzle)

The shroud made of refractories in the form of tube is mounted at the top of the SN lower nozzle brick to transfer molten steel to the tundish without exposing the steel to air. The shroud, as long as 1 m, requires mechanical and thermal spalling resistance to accommodate a sudden stream of molten steel through the inside of the shroud. At the early stage the shrouds were molded by casting with fused silica, which has a low thermal expansion, but to meet to sequential continuous casting process, alumina-graphite-fused silica refractories molded by isostatic press have recently become highlighted because of their excellent spalling and corrosion resistance. As demands for a longer service life of sequential continuous casting grow, efforts have been made to fully preheat before use or to obtain shape of brick less breakable. Along with these practices, as a raw

Table 9. Typical properties of lower nozzle brick.

Material	Burned		Unburned		
	ZRD-SNSZ	HRD-SNE	RMC-A115	RMC-A114	RMC-MS303
Bulk density	3.15	2.70	2.45	2.65	2.80
Apparent porosity (%)	19.0	20.0	7.5	10.0	9.0
Cold crushing strength (kg/cm ²)	550	1 150	1 000	850	1 400
Modulus of rupture (kg/cm ²)					
{at room temp.	—	100	230	190	200
{at 1 400 °C (2 550 °F)	—	60	100	90	100
Thermal expansion (%)					
{at 1 000 °C (1 830 °F)	—	—	0.34	0.43	—
{at 1 500 °C (2 730 °F)	0.65	0.85	—	—	1.4
Chemical composition (%)	Al ₂ O ₃	87	60	80	17
	SiO ₂	12	35	15	MgO : 77
	ZrO ₂	—	—	—	—
	C	—	4	4	4
Remarks	Spalling resistance, pitch impregnated, smoke	Corrosion resistance, pitch impregnated, smoke	For general use, applicable to CC and IC, no-smoke	High corrosion resistance, applicable to CC & IC, no-smoke	High corrosion resistance, no-smoke

Table 10. Typical properties of SN filling materials.

Material		Silica sand		Natural dolomite	Lime-carbon
		YKS4	YKS23	YKC4	YKC6
Grain size (%)	2~1 mm	31.0	90.0	49.0	49.5
	1~0.5 mm	68.4	8.0	46.2	40.3
	0.5~ mm	0.6	0.8	4.8	10.2
Chemical composition (%)	SiO ₂	89.5	95.7	1.1	1.1
	Al ₂ O ₃	5.6	2.7	0.2	—
	R ₂ O	2.7	1.2	—	—
	CaO	0.2	0	34.6	87.9
	MgO	0.2	0	18.1	0.8
	F. C	—	—	—	8.1
Contacting surface with molten steel		SiO ₂ -R ₂ O glass formed		FeO-CaO low melting point materials formed	

material, improvements in quality and grain size of alumina in the matrix have also been made.²³⁾ For the part contacted with molten steel in the tundish, which has a significant influence on its life, simultaneously molded double layer shroud reinforced with highly corrosion-resistant zirconia-graphite are now widely employed. In Table 11, typical properties of a shroud are described.

4. Submerged Nozzle

Submerged nozzles made of refractories in the form of tube leads the molten steel into the continuous casting mould from the tundish, without exposing the steel air. As for the shroud, the submerged nozzle must be provided not only with corrosion and spalling resistance but also with resistance to CC powder corrosion, and most importantly with a countermeasure for nozzle clogging, to meet requirement for the in-

Table 11. Typical properties of shroud.

Portion	Body			Slag line
Material	AGL104	AGL233	AGL324	ZG301
Bulk density	2.24	2.27	2.12	3.20
Apparent porosity (%)	15.9	15.9	16.1	17.0
Cold crushing strength (kg/cm ²)	232	273	198	240
Modulus of rupture (kg/cm ²) at room temperature	80	95	62	70
Thermal expansion (%) at 1 000 °C (1 830 °F)	0.26	0.27	0.20	0.33
Corrosion index				
{Slag-metal interface	100	75	115	40
{Metal portion	100	45	120	—
Chemical composition (%)				
{F. C+SiC	33	32	37	27
{Al ₂ O ₃	44	46	35	—
{SiO ₂	21	17	26	—
{ZrO ₂	—	2	—	68
Remarks	Original	Corro- sion resist- ance	Spalling resist- ance, ap- plicable without preheat- ing	Corro- sion resist- ance

crease in kinds of continuous casting steel and for sequential continuous casting. Isostatic pressed submerged nozzle with alumina-graphite-fused silica have been used.

Any trouble which may by any chance be caused on the submerged nozzles including the powder line that are used on the severe working conditions, will

Table 12. Typical properties of submerged nozzle.

Material	(Body) Graphite-Al ₂ O ₃ -SiO ₂		(Powder line) Graphite-ZrO ₂			(Slit zone)		
	AG109	AG232	ZG51	ZG149	ZG347	AGP319	AGP336	
Bulk density	2.25	2.30	3.30	3.64	3.90	2.18	2.28	
Apparent porosity (%)	17.2	17.5	17.0	18.3	15.7	19.5	18.7	
Cold crushing strength (kg/cm ²)	230	250	280	230	535	200	180	
Modulus of rupture (kg/cm ²)								
{at room temp.	73	85	80	60	100	54	50	
{at 1 400 °C (2 550 °F)	70	80	55	45	—	40	30	
Thermal expansion (%) at 1 000 °C (1 830 °F)	+0.28	+0.34	+0.40	+0.42	+0.46	—	—	
Modulus of elasticity (× 10 ⁴ kg/cm ²)	—	—	10.0	13.0	16.9	7.7	7.6	
Corrosion resistance index								
{Metal portion	100	90	—	—	—	—	—	
{Powder-metal interface	100	—	31	27	17	—	—	
Chemical composition (wt%)	{ F, C + SiC Al ₂ O ₃ SiO ₂ ZrO ₂	25 + 9	27 + 8	17 + 10	12 + 6	8 + 6	26 + 6	21 + 6
		40	52	—	—	—	42	47
		18	10	—	—	—	24	24
		7	—	67	77	82	—	—
Remarks	For general use	For low Al-killed steel	For general use, spalling resistance	High cor- rosion re- sistance	High cor- rosion re- sistance	For general use	Ar blow volume large	

create serious accidents in continuous casting operation itself or will have an enormous influence on the cast steel. The nozzles, therefore, require special management in production line and also stringent non-destructive tests including X-ray inspection so that not any slight defect is overlooked. Similarly, strict inspection is necessary for the raw materials used for the nozzle.

In Table 12, typical properties of submerged nozzle is shown, and in Fig. 14, an example of the material classification of the submerged nozzle with slits, in which three kinds of materials are used.

The actions for the prevention of nozzle clogging are broken into two large categories, an action from the material and another from the mechanism. Conceivable countermeasures for the former are as follows:

- 1) The use of materials not easily wetting with molten steel;
- 2) The use of materials easily corroded with molten steel; and
- 3) Improvement of the inner surface of the nozzle.

Items 1) and 2) actually have many problems and cannot be adopted; only item 3) is applicable by smoothening the inner surface of the nozzle by the addition of zirconia-mullite material.²⁵⁾ Measures in mechanism are considerable effective but still have small problems such as gas film formation.

5. Refractories for Tundish (TD Refractories)

The followings are recent topics related to the TD refractories:

- 1) Scale-up of TD capacity: for sequential continuous casting process and for the acceleration of separation of non-metallic inclusions from molten steel by floating;

Fig. 14. Example of material zones of submerged nozzle with slit.

- 2) Apply of basic refractories to the TD lining: improvement in corrosion resistance and steel quality;
- 3) Employment of dam block: separation of non-metallic inclusions; and
- 4) Hot TD rotation: energy saving, reduction in number of TD.

No special kind refractories but fireclay brick are used for TD lining. High alumina bricks have a promising future in the coming TD hot rotation. The coating material in direct contact with molten steel is specially important. To date, boards have also been applied for this purpose, but these are presently being replaced with basic coating material. The coating installation method is changing from trowel to gunning to meet scale-up and hot rotation of tundish and with improvement of gunning equipment.

Table 13. Typical properties of TD coating materials.

Installation	Troweling		Gunning	
Mark	KCT-M102	KCT-MD3M2	TDG-MF2	TDG-M6
Type of bond	Phosphate	Phosphate	Silicate	Phosphate
Chemical composition (%) $\left\{ \begin{array}{l} \text{MgO} \\ \text{SiO}_2 \\ \text{Al}_2\text{O}_3 \end{array} \right.$	91	80	90	90
	5	10	5	4
	0.5	8	1	—
Grain size $\left\{ \begin{array}{l} \text{Max. grain (mm)} \\ +1 \text{ mm (\%)} \\ -0.21 \text{ mm (\%)} \end{array} \right.$	3	1	2	2
	35	+0.5 mm 13	25	25
	45	68	38	38
Permanent linear change (%) 1 500 °C (2 730 °F)×3 h	−1.50	−2.33	−1.46	−2.02
Bulk density $\left\{ \begin{array}{l} 110 \text{ °C (212 °F)} \times 24 \text{ h} \\ 1 \text{ 500 °C (2 730 °F)} \times 3 \text{ h} \end{array} \right.$	2.29	1.60	2.17	2.20
	2.36	1.65	2.21	2.18
Modulus of rupture (kg/cm ²) $\left\{ \begin{array}{l} 110 \text{ °C (230 °F)} \times 24 \text{ h} \\ 1 \text{ 500 °C (2 730 °F)} \times 3 \text{ h} \end{array} \right.$	30	14	28	17
	65	19	53	23
Thermal conductivity (kcal/m·h·°C) at 1 200 °C (2 190 °F)	1.2	0.58	1.2	1.2
Additional water (add.%)	15~17	15~17	16~17	17~18
Remarks	Insulation		For hot gunning [~150 °C (300 °F)]	For hot gunning [100 °C (212 °F)~]

Photo. 3. Gunning by TUNGUN.

Table 13 shows typical properties of the coating materials for trowelling and for gunning. The development of automatic gunning machines²⁶⁾ allows labor and energy to be saved greatly, and in addition, the gunning with material improvement (hot gunning) will bring about a larger merit as compared with the conventional magnesia boards. In Photo. 3, the gunning operation with a large TD by automatic gunning machine is shown. With this method, there is almost no rebound loss, and material cost saving is secured.^{26,27)}

6. Problem of Continuous Casting Refractories

It is well recognized that there are always demands toward refractories for cost reduction and for accommodation of the requirements of steel quality upgrading. The point at which the refractories for continuous casting are different from other refractories besides the above described feature is that the former are used with emphasis placed on their functioning, as was discussed in the item of the submerged nozzles. In an extreme sense, they are required to possess high

reliability in functioning as machine parts do. The manufacture of the refractories starting with a raw material inspection, is carried out with the support of thorough process controls and is finalized with a shipping inspection in quality and shapes, and, in particular, non-destructive tests are securely implemented on a piece by piece. We are fortunate to be able to use various highly developed, fully reliable non-destructive instruments and to give high reliability to customers. At the same time, CC refractories should be further improved and developed to be higher in performance.

VI. Problem in the Refractories Industry

“Trends of Steelmaking Refractories” accompanied with the technologies of the individual iron and steel making process, have been briefly discussed. The main points of the problem in manufacturing those refractories are summarized as follows:

(1) Raw Materials

Refractories used natural flake graphite have been rapidly increasing as mentioned before, but such graphite may not be easily obtainable in respect of quality although it can be obtained in respect of quantity, which will raise the price of the graphite. An increase in the use of pitch or resin to refractories involves environmental problems and requires protection measures.

(2) Mixing and Kneading

There are problems in the mixing of raw materials which are greatly difference in gravity from each other, method for uniform distribution of little amount additives, suitable technique and equipment for mixing and kneading.

(3) Molding

It is natural to employ an isostatic press for shroud and submerged nozzle. Because the quality of un-

Table 14. Comparison of properties between MgO-C bricks by molding machine.

Molding machine	Content	Apparent S. G.	Bulk density	Apparent porosity (%)	Cold crushing strength (kg/cm ²)	Corrosion index	dimension of oxidized layer (mm)
300 t VFOP	After curing	3.09	2.83	8.5	630	92	3.5
	After burning at 1 400 °C in reducing atmosphere	3.20	2.79	12.8	520		
300 t FOP	After curing	3.10	2.78	10.2	550	100	3.9
	After burning at 1 400 °C in reducing atmosphere	3.20	2.74	14.4	430		

Remarks: Corrosion test condition: Rotating corrosion, at 1 450 °C×3 h, desiliconized slag 80 % +BF slag 20 %
Oxidation test condition: Test piece 50 mm cubicle, temperature 1 200 °C×3 h, electric furnace

burned bricks depends on the molding process, they should be molded under high pressure to make their bulk density as high as possible. In addition, the prevention of lamination is important and vacuum molding is more effective for it. In Table 14, the comparison of the capacity of a vacuum friction press with the conventional press is shown, and its improvement in various properties is evident from these data. Some tuyere brick for duplex blowing have a piece weight of 200 kg (440 lbs.) or more; a high quality is not obtainable unless with a large vacuum molding press.

(4) Burning

Burning at extremely high temperature (more than 1 800 °C (3 270 °F)) will be required to obtain high-quality, high-performance refractories for secondary refining process. Table 15 indicates the influence of burning temperatures on magnesia-chrome rebonded brick, and their significant improvement in hot modulus of rupture is observed from these data.

(5) Machining

Introduction of automatic machining machines is necessary for labor saving, because of increase in machining processing of refractory brick such as tuyere brick assembling, SN plate brick, shrouds, and submerged nozzles.

(6) Inspection

Applications of non-destructive testing equipment are required for ensuring reliability of the refractories.

VII. Monolithic Refractories (Monolithic Refractories for Repair)

For the reduction of the consumption of refractories, extension of the service life of each processing furnace is required. Hot repair process has been introduced as the most important technology and has widely been applied at this time. Monolithic refractories, are best suited to this process, are now being vigorously investigated in order to develop better products to meet the requirements. At the same time, the research and development of installation equipment have been vividly promoted for saving labor, energy and resources, because monolithic refractories never give good performance unless the installation process has been properly carried out.

1. Monolithic Refractories for Hot-iron Pre-treatment Process

The case of molten iron pre-treatment in torpedo

Table 15. Comparison in properties by burning temperature.

Burning temperature	Normal temperature burning (standard—100 to 130 °C)	High temperature burning (standard)	Ultra high temperature burning (standard + 100 to 130 °C)
Apparent S. G.	3.78	3.77	3.77
Bulk density	3.30	3.32	3.33
Apparent porosity (%)	12.6	11.9	11.7
Cold crushing strength (kg/cm ²)	1 020	1 080	1 140
Modulus of rupture (kg/cm ²) at 1 480 °C	90	130	185
Remark : Chemical composition of sample brick (rebonded brick) (%)	SiO ₂ 1.2 Al ₂ O ₃ 6.5	Fe ₂ O ₃ 6.5 Cr ₂ O ₃ 20.8	CaO 0.6 MgO 64.4

Table 16. Typical properties of repairing material for torpedo ladle.

Mark		G-L1	TP-1
Chemical composition (%)	SiO ₂	11.5	11.5
	Al ₂ O ₃	64.0	66.0
	SiC	13.5	13.5
	F. C	—	2.5
Permanent linear change (%)	1 500 °C×3 h	+0.38	−0.09
Bulk density	110 °C×24 h	2.28	2.48
	1 500 °C×3 h	2.23	2.54
Modulus of rupture (kg/cm ²)	110 °C×24 h	46.9	43.7
	1 500 °C×3 h	51.8	109.2
Hot modulus of rupture (kg/cm ²)	1 450 °C×1 h	12.1	7.6
Remarks		For gunning	For trowelling

ladle has been rapidly increasing. Treatment agent are mainly injected through a lance into the molten iron to be mixed. This injection causes a severe wear to the lining brick, the repair of which is badly required to prolong its service life. Table 16 shows

the properties of repairing material showing lives of more than 50 heats. It goes without saying that the cleaning of the inside of the ladle before repair is important. Further reduction of the maintenance procedure for torpedo ladle and prolongation of its life are at present being attained by means of incorporating inner-scope, recently developed for the ladle, with hot gunning machines.

2. Monolithic Refractories for B.O.F.

The principal method of repair for B.O.F. is hot gunning, and this method is highly evaluated for its contribution to the prolongation of service life. The development of mobile hot gunning machines pioneered these of various other installation machines.^{28,29)} Future gunning repair should be studied not only from the material, but also from other aspects, such as installation, curing, etc. For instance, Mg-C gunning material shown in Table 17 could achieve a life of 4 to 6 heats by taking enough hot curing time. Flame gunning as a new technology for repairing has recently been discussed for practical use. In addition, repairing materials and devices for tap holes have been developed in order to adjust the molten steel stream in tapping.

3. Monolithic Refractories for Ladle Repair

The repair methods comprise casting or gunning at room temperature, and hot gunning.³⁰⁻³³⁾ Automatic gunning machines, permitting repair both while cold and while hot, are now in operation. Most of the refractories are SiO₂ materials containing zircon. In the future, high alumina or basic refractories will be developed to meet the requirements of clean steel.

4. Monolithic Refractories for Ladle Refining Process

As the legs and snorkels of DH and RH are always severely corroded, the scheduled lives are barely maintained by the repeated repairs.³⁴⁾ The repair methods include gunning, injection, patching, etc. A gunning machines equipped with vertical nozzles to repair the inside and outside of the tube, are now available. Excellent corrosion resistant castable are usually applied as lance castables for molten steel refining, because this refractory incurs severer corrosion compared with molten iron treatment.³⁵⁾ In Table 18, the properties of the lance castable for molten steel refining are shown.

VIII. Conclusion

On the occasion of the reception of the Asada Prize for the "Refractories for Steelmaking and Continuous Casting Process, and Development of Sliding Gate Nozzles", I have outlined "Trend in Steelmaking Refractories" in this paper within the scope of the title. However, I have to apologize for running past each subject without discussing details. I am afraid I spread myself too thin.

As I mentioned in Introduction, the development of technologies in the steelmaking industry is increasingly gaining speed and things are rapidly changing in the face of the second turnabout period of the industry.

Table 17. Typical properties of gunning material.

Mark		MHT-NP18C
Chemical composition (%)	MgO	76.3
	CaO	8.2
	F. C	5.0
Grain size (%)	+1 mm	33
	−0.044 mm	30
Hot casting at 1 400 °C	Modulus of rupture (kg/cm ²)	33
	Crushing strength (kg/cm ²)	53
	Apparent porosity (%)	38
	Bulk density	2.07

Table 18. Typical properties of lance castable for molten steel treatment.

Material		Special castable LC41-3H	High strength castable CT-170H
Maximum service temperature (°C)		1 800	1 700
Chemical composition (%)	Al ₂ O ₃	98	71
	SiO ₂	—	27
	(CaO)	1.1~1.3	—
Additional water (%)		5.0~5.5	6.5~7.5
Permanent linear change (%)	1 500 °C (2 730 °F) × 3 h	−0.10	+0.35
Bulk density	110 °C (230 °F) × 24 h	3.12	2.56
	1 500 °C (2 730 °F) × 3 h	3.08	2.53
Modulus of rupture (kg/cm ²)	110 °C (230 °F) × 24 h	45	70
	800 °C (1 470 °F) × 3 h	35	90
	1 500 °C (2 730 °F) × 3 h	180	110
Hot modulus of rupture (kg/cm ²)	1 400 °C (2 550 °F) × 1 h	40	30

At this historical moment I pledge to make all possible efforts to develop refractories that meet the needs of the steelmaking industry.

Thank you.

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