Technology

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Repairing Technology of Refractories

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Abstract

Many refractories are lined for vessels and furnaces in the ironmaking and steelmaking process. They wear out once the thickness for the initial lining reaches the safety limit. The life is extended by performing partial replacement of bricks or repair. Various repair methods are used depending on how the repair material is transported to the repair location and the temperature at the repair location. This paper outlines the typical repair technology, and then reports on a new gunning repair technique using continuous instantaneous kneading technology developed by Nippon Steel Corporation and Krosaki Harima Corporation.

1. Introduction

Many refractories are used in the upward and downward processes of steel production. Once completed, refractory installations are used while being partially patched or repaired until they reach their residual thickness limits or structural limits. For example, converters have MgO bricks installed as permanent lining and MgO-C bricks as wear lining. When the converters reach their residual wall thickness limits after blowing so much heat, they are relined with refractories. To extend the life of converters, worn tap holes are replaced and worn walls are repaired by gunning, hot casting, or thermal spraying. Once completed, these refractory installations are used until they reach their service limits but are also partially replaced or repaired to prolong their service life. In this report, we summarize our refractory repair techniques and report the new gunning repair techniques Nippon Steel Corporation has jointly developed with Krosaki Harima Corporation.

2. Refractory Repair Techniques

2.1 Types of refractory repair techniques

Various repair techniques are practically applied. Principal refractory repair methods are dry gunning, wet gunning, thermal spraying, injection, hot casting, and patching. The repair refractory mixture may be transported by high-pressure air, pumped, or carried to the repair area. Repair is called hot repair when the repair area is hot and cold repair when the repair area is cold. Some repair methods are performed hot, some are performed cold, and some are performed both hot and cold. In this section, we describe in detail typical repair methods, or dry gunning, wet gunning, thermal spraying, injection, and hot casting.

(1) Dry gunning

Figure 1 shows the configuration of a dry gunning system. A particle size-adjusted material and a binder-mixed powder are drawn in required amounts from the material tank, fed by high-pressure air to the nozzle, mixed with water at the tip of the nozzle, and gunned against the repair area. This system is simple in construction and easy to maintain. The refractory material is selected to suit the repair area. Silicate, phosphate, resin, and pitch are used as binders. Silicate and phosphate binders can be used in a high-temperature range in view of their hardenability. This simple system is usable both cold and hot, and widely utilized. Since water is added at the nozzle tip, however, the material may not be fully mixed with the water and the water content may increase.

(2) Wet gunning

The wet gunning method is available as a means for solving the mixing problem of dry gunning. **Figure 2** shows the configuration of a wet gunning system. A water-kneaded refractory mixture is pumped to a nozzle, added with a set accelerator at the tip of the nozzle, and gunned against the repair area. An alkaline solution is used as a set accelerator. The pump may be a squeeze type, double-piston type, or screw type. Since the shotcrete mixture is kneaded beforehand, it can be reduced in the water content and porosity and can be improved in durability as compared with the dry gunning mixture. On the other hand, the shotcrete mixture must contain more water for pumping than the castable mixture. Since the shotcrete mixture is kneaded and then pumped, it may remain in the hose or the like after installation and increase the material loss. Nippon Steel reported the refractory lining improvements achieved by applying the shotcrete method to torpedo cars at the Kimitsu Area (hereinafter referred to as Kimitsu) of East Nippon Works[1)] and at the Nagoya Works.[2)]

(3) Injection

The injection method pumps the kneaded mixture to the installa-

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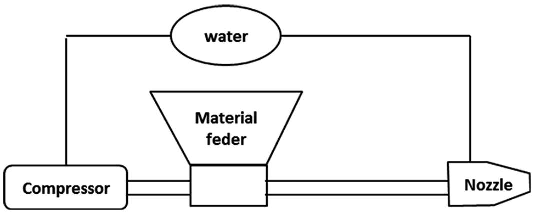


Fig. 1 Outline of dry gunning system

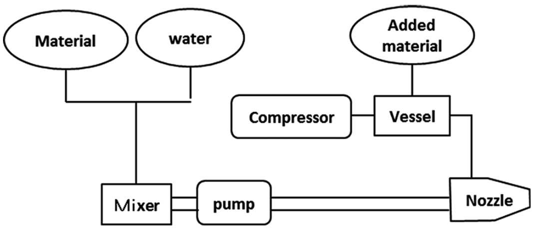


Fig. 2 Outline of wet gunning system

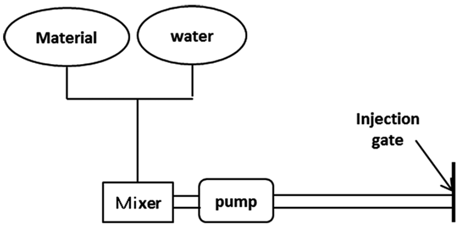


Fig. 3 Outline of injection process

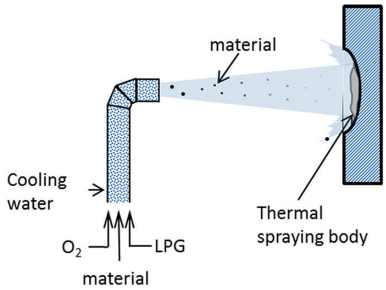


Fig. 4 Schematic diagram of lava flame method

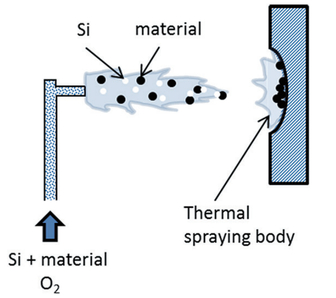


Fig. 5 Schematic diagram of thermite gunning method[3)]

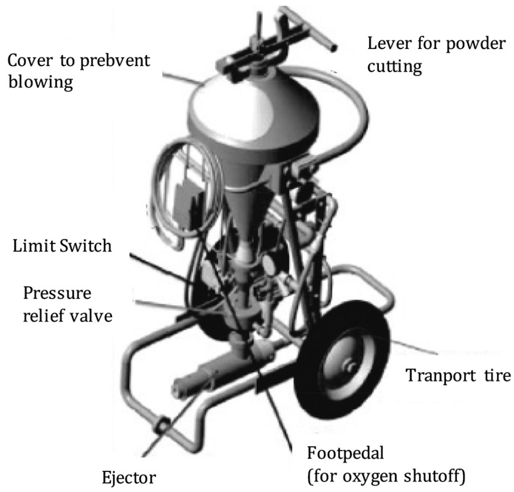


Fig. 6 Example of thermite gunning method repair equipment[3)]

tion position and injects the material into the repair area as shown in **Fig. 3**. The repair of the RH vacuum degasser snorkels and lower vessel circulation pipe can be cited as an application example of shotcrete repair. A steel core is placed in the repair area and the kneaded mixture is injected between the residual brick lining and the core. Another example is the injection of refractory material between the replacement bottom and the converter proper when the bottom of the converter is replaced. Still another example is the injection of refractory material between the steel shell and the brick lining of hot blast stoves and blast furnaces.

(4) Thermal spraying

Thermal spraying refers to the method of repairing a lining area by spraying a molten or semi-molten refractory material to the repair area. Two thermal spraying methods are mainly applied to repair refractory linings. One is the lava flame method. As shown in **Fig. 4**, a finely crushed refractory material is discharged together with oxygen and propane, melted by the heat of the flame, and sprayed to the repair area. The other is the thermite gunning method. As shown in **Fig. 5**,[3)] the refractory material is mixed with silicon metal and carried by oxygen. The thermite reaction between the metal and oxygen is caused by the heat of the repair surface and used to bond the refractory material to the repair surface. The lava flame method was practically applied at Nippon Steel in the 1980s and used to repair the linings of converters,[4, 5)] steel ladles,[6)] and coke ovens.[7)] In the 2000s, Nippon Steel developed diagnosis and repair equipment, a diagnosis and lava flame combination, and deployed it throughout its steelworks.[8)] As shown in **Fig. 6**,[3)] the thermite gunning equipment is simple and the operator can handle its nozzle. The thermite gunning method is mainly used to repair the walls of coke oven openings.

(5) Hot casting

For repair by hot casting, the refractory material is mixed with phenol resin or pitch as a binder, bagged, and thrown into the furnace. The binder is softened and hardened to install the refractory lining. In the hot state, the hot casting material is fluid but the evaporation of the volatile matter in the binder increases the hardening time. The hot casting method cannot be thus applied to vertical walls and other such areas. It is mainly used to repair the linings of converters.

2.2 New gunning methods

In the previous sections, we have introduced conventional repair techniques. Dry gunning is often used for making hot repairs. Dry gunning and wet gunning are often used for making cold repairs. These methods have such problems as poor kneadability and large material loss. Nippon Steel and Krosaki Harima jointly developed new gunning methods to solve these problems. The new methods are described below.

2.2.1 Continuous and instantaneous kneading and gunning repair technique (named "hot-quick mixing and mist injection" and abbreviated as H-QMI)[9, 10]

(1) Overview

Dry gunning is used for making hot repairs. The addition of water just before the nozzle creates the following problems: (i) The refractory material is not thoroughly kneaded and excess water tends to be added to make up for this condition. The result is a high-porosity or uneven-quality refractory lining. (ii) The adhesion of the gunning refractory is difficult to achieve. (iii) Dust is generated. To solve these problems, we developed a continuous and instantaneous kneading mechanism and built it into a conventional dry gunning system to complete a new system named "hot-quick mixing and mist injection" and abbreviated as H-QMI. The H-QMI system helped to achieve: (i) lower water content, (ii) higher bulk density, (iii) better adhesion, (iv) higher durability, and (v) lower dust generation.

Figure 7 shows the introduced H-QMI system. ① A mist water addition mechanism[11] atomizes water by pressured air and adds the mist water to and wets the refractory material transported. ② To impart a shear force higher than the cohesive force of the fine powder, the fine powder is kneaded by kneading pins rotating at a high speed of 1 500 rpm to produce acceleration two orders of magnitude higher than in the past. The material kneaded in the gaps between the kneading pins and the outer rotor is thrown against the side wall by the centrifugal force of the kneading pins and is moved down while being sheared by the kneading pins. ③ The kneaded material is collected in the lower cone and again pneumatically carried through the transfer line to the gunning nozzle.

Figure 8 shows the configuration of the H-QMI system. The H-QMI system is composed of: ① a constant-rate feeding mechanism for the dry powder, ② a dry powder transport line, ③ a mist water addition mechanism, ④ a continuous and instantaneous kneading mechanism, ⑤ a slurry transport line, and ⑥ a gunning nozzle. The gunning capacity is a maximum of 100 kg/min. The added water content is 20 to 30% lower than in the past.

(2) Application to converters

Figure 9 shows the appearance of a self-traveling hot gunning machine fitted with the continuous and instantaneous kneading mechanism and intended for use on converters. An additional requirement for use on converters is nozzle cooling. Another is the ease of adjusting the water content to suit the gunning position and surface in order to secure optimum adhesion. The gunning nozzle is retrofitted with a mechanism to add water as required. The gunning capacity is 100 kg/min and the optimum added water content is 28 to 35%. Basically, conventional dry gunning materials can also be used on converters.

Figure 10 compares the physical properties of refractories installed with and without the H-QMI system. It is evident that the application of the H-QMI system has substantially improved the quality of the installed refractory linings. **Figure 11** shows the H-QMI gunning repair of a converter trunnion lining and the residual conditions of the refractory lining installed there. There is no installation difficulty. As compared with dry gunning, the water content of the installed lining is reduced by uniform dispersion of water and the necessary installed lining thickness is secured by the improvement in adhesion. The water content reduction allows the charging of hot metal in a matter of a few minutes after the refractory installation and shortens the repair time. While the trunnion linings installed by

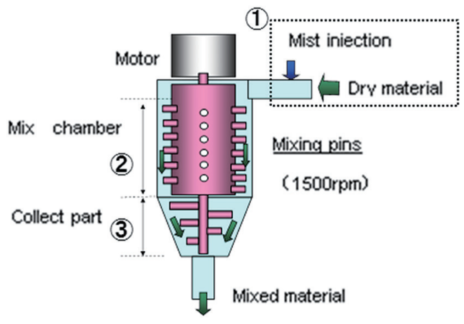


Fig. 7 Mixing mechanism of H-QMI

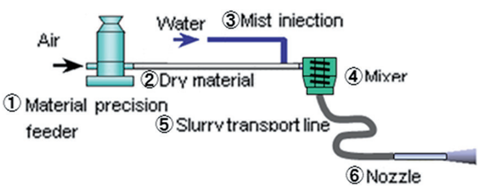


Fig. 8 Schematic diagram of H-QMI

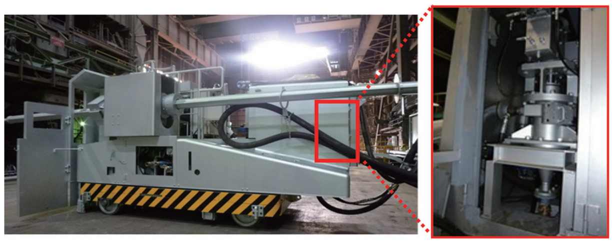


Fig. 9 Gunning machine with H-QMI for converter

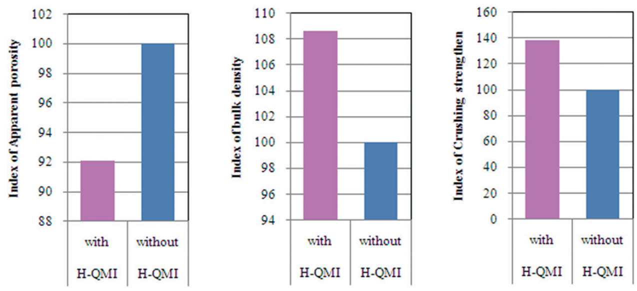


Fig. 10 Effect of H-QMI in three physical properties of casted gunning slurry mixed with or without H-QMI

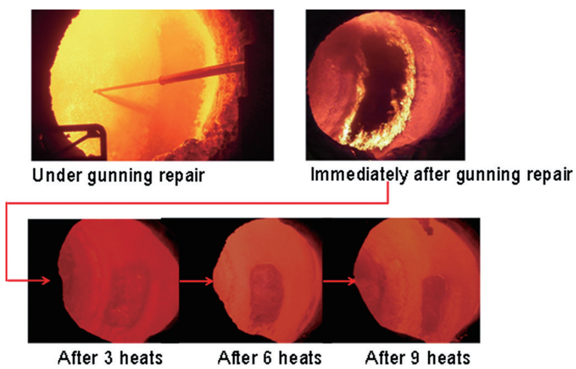


Fig. 11 Gunning performance and residual materials in trunnion zone of a converter

the conventional dry gunning method lasted 4 to 5 heats, those installed by the H-QMI method still remained after 9 heats and were confirmed to have twice longer durability. The H-QMI system is implemented for converters at the Muroran Works (hereinafter referred to as Muroran) and at the Kashima Area of East Nippon Works.

(3) Application to steel ladles

Figure 12 shows the H-QMI system for steel ladles. Steel ladles do not need a large amount of nozzle cooling water like converters, so that their refractory linings can be further reduced in the water content. A set accelerator addition line is separately installed to further improve the quality of installed refractory linings. The set accelerator is drawn and fed at a constant rate to the nozzle to increase the dispersibility of the set accelerator. The gunning capacity of the H-QMI system is 20 to 40 kg/min and the optimum added water content is 10 to 13%.

The refractory materials for steel ladles are based on Al_2O_3-MgO and added with ultrafine material and water-reducing admixture to improve kneadability and to reduce the water content. **Figure 13** shows the correlation between the added water content and the ultrafine material addition content. It is evident that the addition of the ultrafine material can reduce the added water content to an intermediate level between casting refractories and dry gunning refractories. As a result, the H-QMI system significantly improved the properties of installed refractory linings under the hot gunning conditions and increased their durability. **Table 1** shows the typical chemical composition of the H-QMI material. **Figure 14** compares the refractory linings installed by the dry gunning method, H-QMI method, and casting method in apparent porosity and modulus of rupture. Reduction in the added water content and improvement in kneadability increased the density and modulus of rupture of the refractory lining installed by the H-QMI method as compared with those installed by the dry gunning and casting methods.

Figure 15 shows the microstructures of linings installed by the H-QMI method and the conventional dry gunning method. Comparison of the two refractory linings shows that the refractory lining installed by the H-QMI method is lower in water content and higher in density. Consequently, the grains are densely packed and the voids between the matrices are reduced. **Figure 16** shows the H-QMI gunning repair of a steel ladle sliding nozzle tuyere and the residual conditions of the refractory lining installed there. The lining installed by the H-QMI method lasted 5 to 6 heats against 2 to 3 heats for the lining installed by the conventional dry gunning method and was confirmed to be twice as durable. The H-QMI method

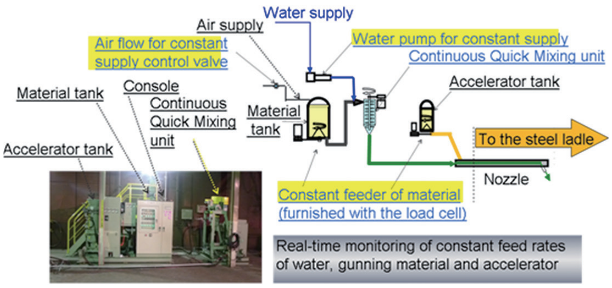


Fig. 12 Gunning machine with H-QMI for ladle

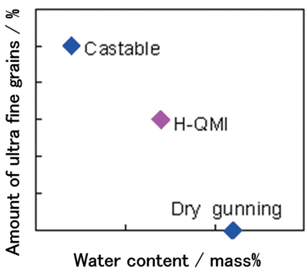


Fig. 13 Correlation between water amount in slurry and amount of ultra fine grains in three different application methods

Table 1 Typical properties of the material used for H-QMI

Installation method	H-QMI
Application	Ladle
Chemical compositions / mass%	
Al_2O_3	74
MgO	15
SiO_2	5

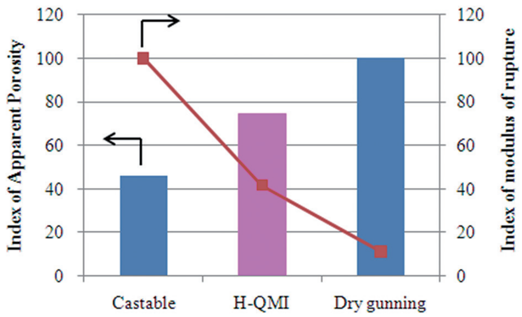
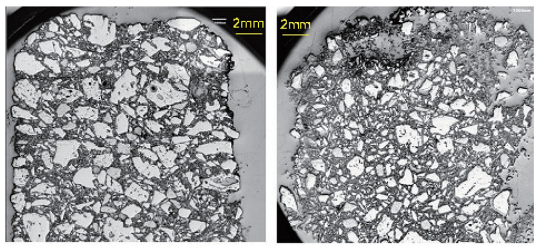


Fig. 14 Comparison of apparent porosity and modulus of rupture of the material applied in three different application methods



(a) H-QMI (b) Dry gunning

Fig. 15 Microscopic section view of the material gunned (a) H-QMI method and (b) Dry gunning method

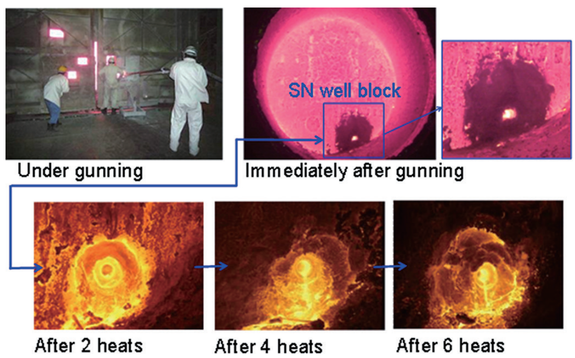


Fig. 16 Gunning performance around the sliding nozzle (SN) well block of hot steel ladle and durability in the hot services

has been applied to steel ladles also at Kimitsu[12, 13] and has proved effective in the service life extension and cost reduction of the steel ladle linings.

2.2.2 Automatic repair technique (named "quick mixing shot" and abbreviated as QMS)[14, 15]

Cold repair calls for the added water content to be reduced to increase the density and durability of the installed refractory lining. The conventional shotcrete method adds water to a dry powder material, kneads the mixture, pneumatically or otherwise feeds the kneaded mixture to the tip of a nozzle, and guns the kneaded mixture to the repair area. The water content, however, must be increased to impart pumpability and the refractory lining thus installed lacks in durability. Also, washing after the installation takes time. Nippon Steel developed jointly with Krosaki Harima an automatic repair technique (named "quick mixing shot" and abbreviated as QMS) by making use of the aforementioned H-QMI technique.

(1) Mechanism of QMS technique

The H-QMI technique described in the previous section is advantageous in continuous kneading. When it is directly applied for making cold repair, it presents problems such as (i) insufficient kneading and (ii) restriction of the distance to transport the kneaded high-viscosity mixture to the gunning nozzle. The retention time of the mixture in the kneading mechanism was increased to increase the kneading intensity and prolong the kneading time. As shown in **Fig. 17**, a truncated conical outer rotor expanding downward is rotated. The resultant centrifugal force throws the material against the inside surface of the outer rotor and retains the material there. The kneading pins apply shearing, compressing, and stretching forces to the retained material layer and smoothly move down the kneaded material. The kneaded material is repeatedly subjected to these forces during the retention time and can be continuously and instantaneously kneaded.

A mechanism of rotary shot[16] was applied as a mechanism integrating the transport of the kneaded material to the gunning position with the gunning of the kneaded material at the gunning position. Centrifugal force was utilized instead of pressurized air. As shown in **Fig. 18**, the QMS mechanism consists of: (i) a projection disk arranged in contact with the outlet of the outer rotor, (ii) a belt wound around the projection disk and provided with a driven opening, and (iii) a reflective plate to direct the material projected through the opening and to rectify the flow shape of the material. The flow velocity and cross-sectional size of the projected material can be controlled by these mechanism elements to optimize the adhesion property of the material.

(2) QMS material

As compared with the H-QMI technique used for making hot repairs, the QMS technique has improved the kneadability of the material by extension of the retention time of the material in the continuous and instantaneous kneading mechanism. Since the kneading time is shorter than that of batch kneading, however, materials with good deflocculation properties are required. The shotcrete method uses an excessive fine fraction to impart pumpability. The QMS method does not need such excessively fine particles, can reduce the excessively fine fraction, and thus can be expected to improve the physical properties of installed refractory linings. We studied the particle size composition with the excessively fine fraction reduced on the basis of the current shotcrete material and improved the kneading, adhesion, and physical properties of QMS materials. **Table 2** compares the physical properties of refractory linings installed by the QMS method and the shotcrete method. **Figure 19** shows the microstructures of the QMS and shotcrete refractory linings. The QMS refractory lining is found to have lower water content and higher density than the shotcrete refractory lining.

(3) Application to steel ladles

Figure 20 shows the application of the QMS method at the Oita Area (hereinafter referred to as Oita) of the Kyushu Works. The entire QMS system was placed on the steel ladle. The steel ladle is large in diameter. When the kneaded mixture projection section of the QMS system is placed at the center of the ladle, the distance to the repair surface is increased to decrease the adhesion of the QMS

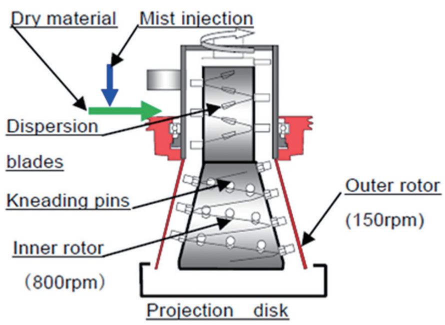


Fig. 17 Schematic diagram of quick mixing equipment

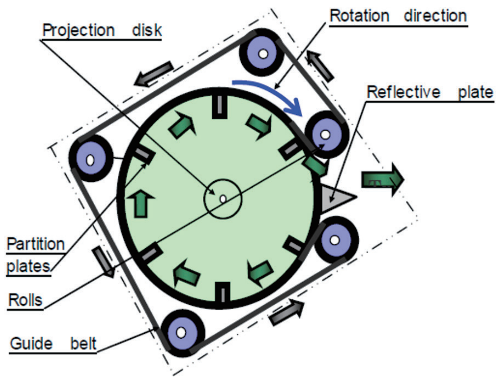
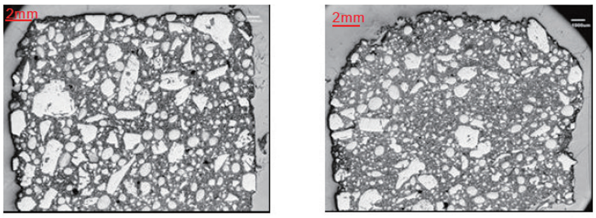


Fig. 18 Projection mechanism

Table 2 Typical properties of QMS and shotcrete material

Installation method	QMS	Shotcrete
Chemical compositions / mass%		
Al_2O_3	82	82
MgO	12	12
Apparent porosity / %		
110°C × 24 h	21.4	23.4
1 500°C × 3 h	26.0	28.6
Bulk density / $g{\cdot}cm^{-3}$		
110°C × 24 h	2.93	2.87
1 500°C × 3 h	2.74	2.68
Modulus of rupture / MPa		
110°C × 24 h	5.1	3.8
1 500°C × 3 h	25.0	18.5
Permanent linear change / %		
1 500°C × 3 h	+1.36	+0.53
1 500°C × 12 h	+1.38	+0.35
Water addition / mass%	7.7	8.8



(a) QMS (b) Shotcrete

Fig. 19 Microstructure of the gunning bodies of QMS and shotcrete

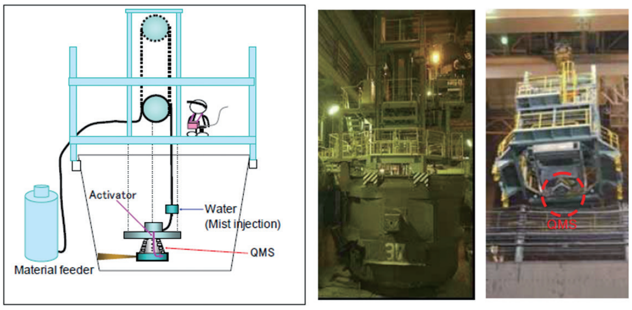


Fig. 20 QMS for ladle in Oita

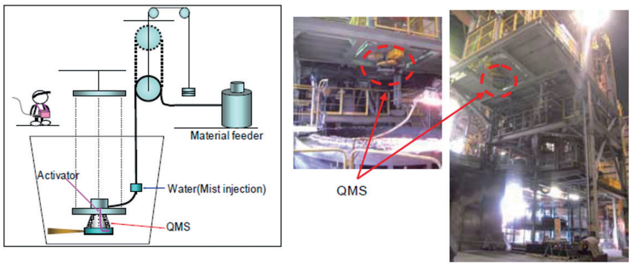


Fig. 21 QMS for ladle in Muroran

material. When the kneaded mixture projection section is placed off center of the ladle, it must be turned. This turning complicates the construction of the QMS system, but the distance to the repair area can be reduced to improve the adhesion of the QMS kneaded mixture to the repair surface. **Figure 21** shows the QMS system introduced at Muroran. The QMS system is mounted on a portal type truck. The portable type truck is moved to adjust the setting of the QMS system on the steel ladle. The QMS kneaded mixture projection section is placed at the center of the ladle. The section is circumferentially turned to install the refractory lining on the ladle. This central arrangement simplifies the setting of the QMS system on the steel ladle, increases the efficiency of refractory installation by the QMS system, and simplifies the QMS system.

(4) Actual application results

Figure 22 compares the durability of ladle linings installed by the QMS and shotcrete methods at Oita. The residual lining thickness ratio after 70 to 80 heats was 50 to 60% for the ladle linings installed by the shotcrete method and 70 to 80% for the ladle linings installed by the QMS method. This confirmed the high durability of the ladle linings installed by the QMS method. Factors considered responsible for this excellent performance are the formation of lower-water content and high-density refractory linings and the formation of uniform linings on the ladles. The changes in the lining life and cost of steel ladles at Oita and Muroran are shown in **Figs. 23** and **24**, respectively. The automatic repair technique Nippon Steel developed by using its H-QMI system has extended the service life of refractory linings and reduced their installation cost.

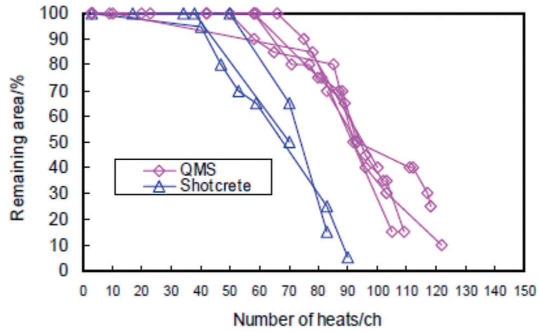


Fig. 22 Comparison of service life of ladle in Oita

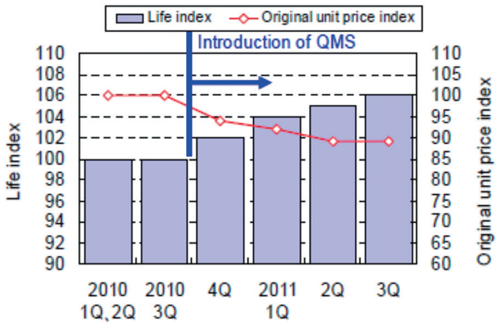


Fig. 23 Change of life and cost in Oita

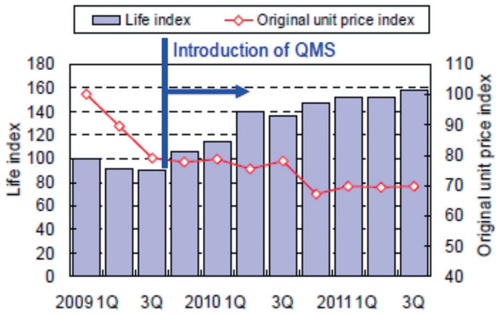


Fig. 24 Change of life and cost in Muroran

3. Conclusions

Repair techniques are essential for the use of refractories in the steel industry. Gunning and thermal spraying have advanced as repair techniques. Nippon Steel has jointly developed with Krosaki Harima the H-QMI technique and applied it for making both hot and cold repairs. As a result, we have successfully achieved substantial refractory lining life and cost improvements.

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