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Development of Refractory Spraying Repair Systems, QMS (Quick Mixing Shot) and H-QMI (Hot Quick Mixing & Mist Injection)

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Abstract

Birth rate is declining and the aging population is rapidly advancing in Japan. Against this background, Nippon Steel & Sumitomo Metal Corporation has mechanized the labor-intensive repair work of refractory lining of iron- and steel-making facilities. Spraying of unshaped refractory has been the principal method of mechanizing refractory repair, wherein it is important to enhance the durability of the sprayed material while enjoying the advantages of mechanization. New refractory repair methods have been developed based on a compact mechanism for continuous rapid mixing and kneading, which dictates the quality of the deposited refractory.

1. Introduction

The iron and steel industry uses various kinds of refractory materials. They are damaged during use and are repaired online in hot or offline in cold. The methods of cold repair include spraying, patching, brick replacing, refilling, and troweling, and those of hot repair include hot spraying, press fitting, patching and baking, and slag coating. Of these, the application of spraying, either in cold or in hot, has expanded significantly over the last years. For stable operation of high-temperature facilities and reduction of refractory costs, Nippon Steel & Sumitomo Metal Corporation has developed various refractory repair methods by spraying. Quick refractory mixing and kneading process is one such technology. It is a mechanized method that combines good workability and high repair quality and is used widely in house as well as outside the company. This paper presents the outlines of the process.

It has to be noted here that the developed process is herein referred to as quick mixing shot (QMS) when used for cold repair and as hot quick mixing and mist injection (H-QMI) when used for hot repair.

2. Conventional Refractory Repair Practice and Problems in Mechanization

2.1 Problems with conventional repair by spraying

When unshaped refractory is used for repair, it is sprayed or cast into molds after mixing and kneading with water. The workability of the material and its durability depend greatly on the amount of water mixed to the refractory in powder: when good durability is aimed at, the water addition is controlled to the minimum required so as to minimize the porosity of the deposited material to increase its density. In contrast, when more emphasis is placed on workability, the water addition is increased to decrease its viscosity so that it can be pumped with as low resistance and as little adhesion in the route as possible. This indicates that durability and workability are incompatible with each other, and the water addition amount is determined in consideration of the object and conditions of each repair work.

More specifically, in cold repair, durability tends to be more important than the ease of work, and the water addition is minimized. In hot repair, on the other hand, workability is more important than it is in cold repair, and water addition tends to be increased. In the present development, in consideration of the relationship between the water amount, material durability, and workability, schematically presented in **Fig. 1**, minimum water addition was aimed at, either for hot or cold repair, for better durability of the deposited refractory layer.

2.1.1 Problems with conventional cold repair method

Figure 2 schematically shows a typical and principal method of refractory repair in cold, known as the shot-cast method; its outlines and problems are explained below. The method consists of the processes of mixing, pumping, and spraying; of these, mixing is independent from the others, and each process requires an operator exclusively. As described in **Table 1**, the method has the following problems regarding the product quality (1) and workability (2 to 5), and there was much room for improvement of product durability

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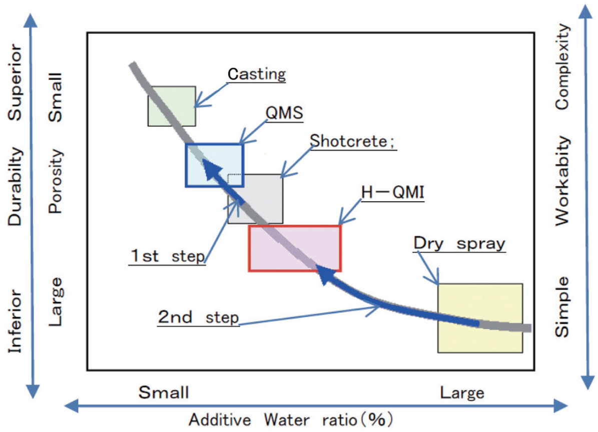


Fig. 1 Effect of additional water content on workability and durability

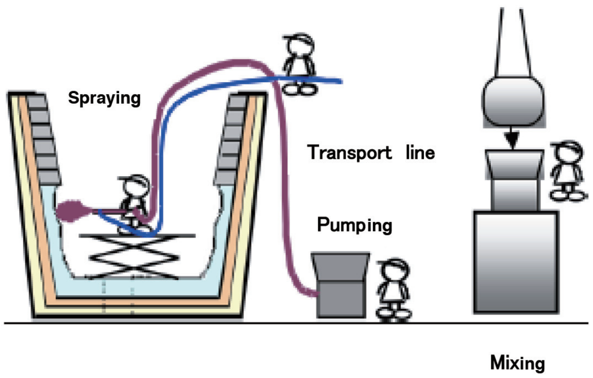


Fig. 2 Conventional cold repairing method

Table 1 Problems of conventional repair technology

Item	Problem
Water addition	Excessive water addition for good pumping
Operability	Three to four operators for mixing, pumping and spraying at separate positions
Environmental condition	Poor, especially for spraying operator
Work capacity	Restricted by environmental condition
Supplementary work	Time-consuming cleaning after use

and labor saving:

(1) Water addition amount: To secure good fluidity for pumping a viscous refractory mixture, the amount of water added at mixing inevitably exceeds the limit required from the viewpoint of the material quality finally obtained.

(2) Number of personnel required: At least one operator is required for each of mixing, pumping, and spraying. (The one at the ladle periphery in Fig. 2 is for tube handling and is omissible by mechanization.)

(3) Poor work environment: Since the refractory mixture is sprayed with air, the environmental condition, especially of the spray nozzle operator who works in a ladle or a similar vessel, is poor owing to the dust from the nozzle.

(4) Limited work capacity: Owing to the limits in the amount and the distance of pumping and the heavy work load due to dust, the heavy hose, and the heat of the spraying operator, the work

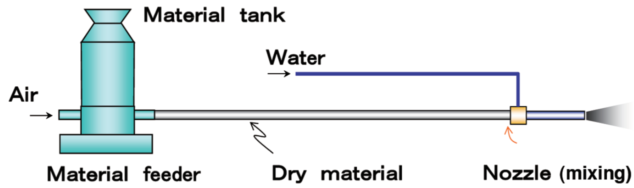


Fig. 3 Equipment for conventional hot repair

rate is naturally limited.

(5) Auxiliary work: The pumped mixture inevitably remains in the hose and has to be cleaned after the work, which involves additional time and labor.

2.1.2 Problems with conventional hot repair method

The outlines and problems of a typical and presently employed method of refractory repair in hot, called the dry spraying method, are explained below (see **Fig. 3**).

The equipment for the method has a simple structure for pumping the material in dry powder with air and adding water immediately before spraying. Since the repair work has to be finished within a short time in a high-temperature environment, the equipment is simple for workability's sake. However, since water is added a little before spraying, the mixing tends to be insufficient and the water amount becomes excessive. As a result, the method has the following problems: (1) poor mechanical properties of the refractory finally obtained, (2) poor adhesion to the surface to repair, and (3) poor work environment due to dust emission.

3. Point of Study for Process Mechanization

3.1 Structure of unshaped refractory material

The word "monolithic" is often used for expressing an object obtained through the formation of unshaped refractory, but under close examination, it is a composite material comprising aggregates and binder after cement solidification (see **Fig. 4**), and the components contribute to its strength, as shown in **Table 2**. It follows therefore that to enhance the durability of such composite material, it is effective to improve the density and strength of the binder, because there is a certain upper limit to the mixing ratio of the aggre-

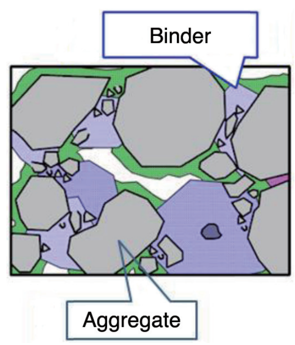


Fig. 4 Microscopic structure model

Table 2 Composite strength sharing

Strength	Binder	Aggregate
Compression	△	◎
Erosion	△	◎
Thermal stress	◎	○

◎: Excellent, ○: Good, △: Poor

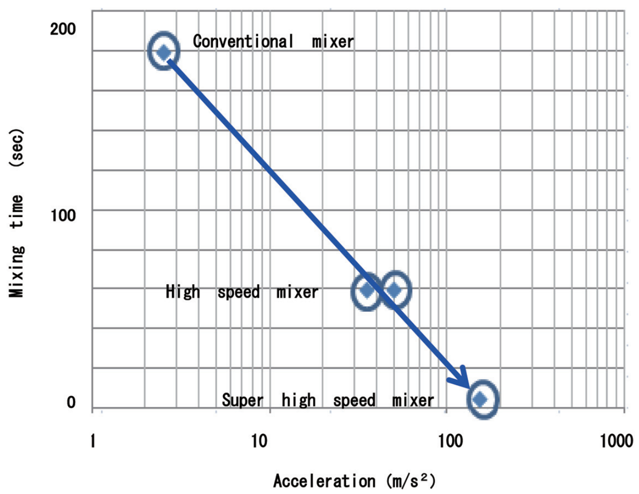


Fig. 5 Acceleration by different mixer types

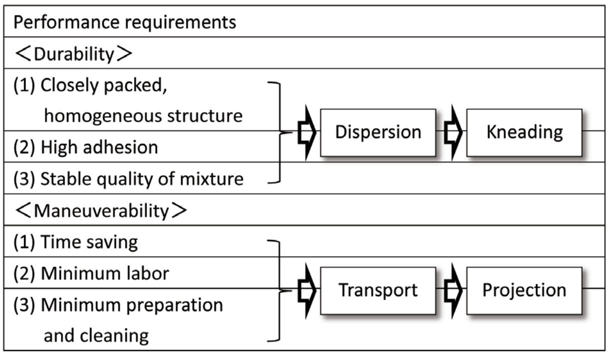


Fig. 6 Performance items required for cold repair

gate. With respect to improvement of work environment, the principal measures are to prevent fine powder of the binder from forming lumps and intensify its mixing with the aggregates.

In consideration of the above properties of the refractory material, a high-speed kneading mechanism was proposed to obtain good mixing with as little water addition as possible. **Figure 5** schematically shows the relationship between the mixing time and the magnitude of rotational acceleration obtainable by different types of mixers. The aim of the study in developing a new type mixer was to realize homogeneous and intensive mixing of the material without segregation by an acceleration larger than that of conventional mixers by three orders of magnitude.

3.2 Development objectives

The performance requirements for refractory repair in cold are listed in **Fig. 6**. The essential requirements for high durability of the product refractory include (1) closely packed and homogeneous structure, (2) good adhesion and (3) stable quality of mixture, especially even moisture distribution. On the other hand, those for good workability are (1) short working time, (2) minimum number of personnel and (3) less auxiliary work. It was thus necessary to work out improvements for each of the mixing, pumping and spraying processes.

4. Development of New Mixer/Kneader and System Formation

4.1 Mechanism for rapid and continuous mixing and kneading

As a method for rapidly mixing and kneading the refractory material, the technology of the Rotary Shot, which Nippon Steel & Sumitomo Metal developed some time ago was applied.[1, 2] By this mechanism, charged refractory containing easily agglomerating very fine powder is effectively dispersed by a rapidly turning inner rotor with many blades planted on the surface, specially designed for mixing quickly solidifying material, and at its lower part, while the mixture is further kneaded by pins on the surface of the inner rotor, it slides downwards at an adequate rate under the centrifugal force on the inner surface of the outer rotor (see **Fig. 7**).

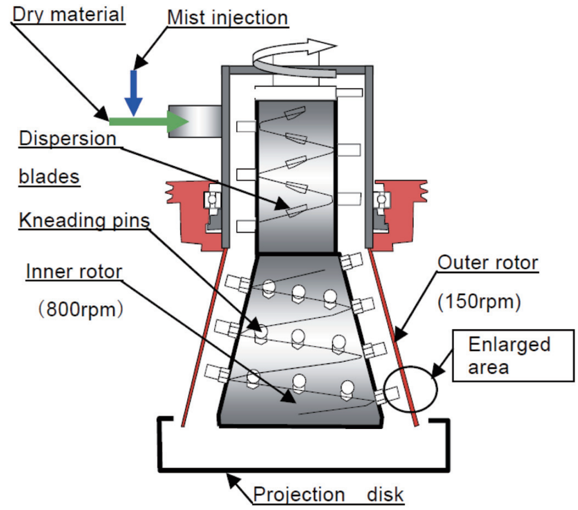


Fig. 7 Mechanism of developed mixer/kneader

Water mist is sprayed to the dry material immediately before entry to the mixer. The upper and the lower part of the mixer/kneader separately carry out the functions of dispersing and kneading the material, respectively. Since the upper part is responsible mainly for evenly dispersing the dry material and the added water, and for this purpose, many mixing blades are provided on the surface of the inner rotor. Then, in the lower part, the slurry of the refractory is thrown onto the inner surface of the outer rotor by the centrifugal force of the pins of the inner rotor, and is kneaded there. To thoroughly knead the slurry containing only a small amount of water, it is effective to make the resident time in the mixer/kneader longer. For this end, the outer casing of the lower part of the mixer/kneader is made to rotate such that the slurry adheres to its inner surface under the centrifugal force. In addition, in order to prevent the slurry to stay here for too long a time, and feed it smoothly to a projector provided downstream, the outer casing has a shape of a truncated cone like a down-turned trumpet so that the slurry is pushed downwards under the centrifugal force.

The kneading mechanism is explained in more detail in **Fig. 8**, where the part of Fig. 7 marked by a circle is enlarged.

(1) A kneading pin is forced into the slurry layer on the inner surface of the outer rotor and applies shear, compression and rolling to it.
(2) Subsequent pins in staggered positions pass following near-by routes to apply the same effects. This rapid kneading process repeats while the slurry slowly slides downwards on the inner surface of the outer rotor.

An optimum combination of (1) the rotation speeds of the inner and the outer rotors, (2) the length and diameter of the kneading pins, (3) their arrangement (number and intervals), and (4) the gap between the pin heads and the outer rotors was looked for to opti-

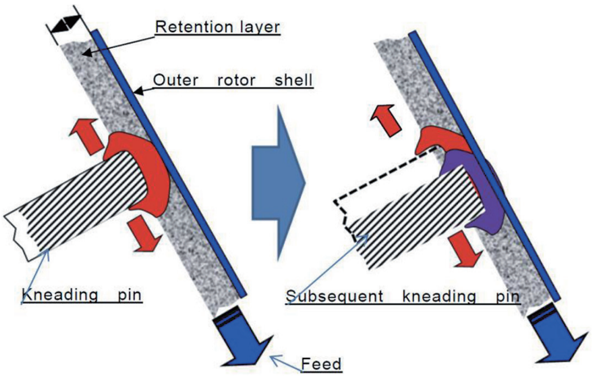


Fig. 8 Hypothesis of improved mixing

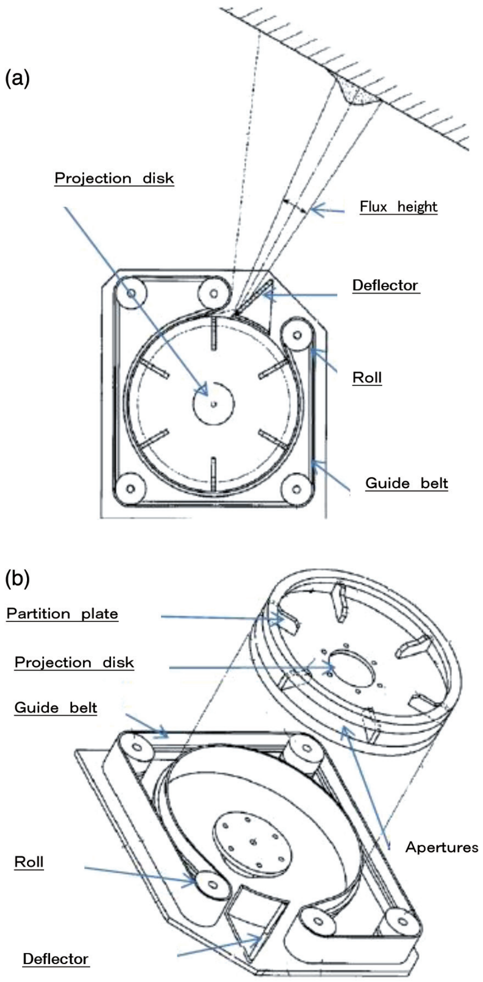


Fig. 9 Appearance of (a) Refractory projection, (b) Assembly of projecting unit

Table 3 Projection conditions and specification

Projection condition	Machine specification and operation
Projection speed	Rotation speed of disk
Bulk size	Number of partition plates
Width and height of flux	Angle of deflector

mally control the resident time of the slurry in the lower part of the mixer/kneader.

4.2 Method and mechanism of projecting refractory mixture

To apply the refractory in low-moisture and highly viscous slurry prepared for good durability in a highly workable manner, it is necessary to transport and project it to the position where it is needed through as short a route as possible. For this purpose, the mechanisms for its transport and application are unified using the mechanism of the rotary shot method, whereby the slurry is not sprayed with air but is projected by centrifugal force.

The slurry projecting mechanism is explained here. As seen in **Fig. 9**, the machine is composed of (1) a projection disc provided coaxially at the discharge end of the outer rotor of the mixer/kneader, (2) a belt wrapping most of the outer periphery of the disc and driven by it, running in a circular route that has an opening for slurry projection and (3) a deflector plate to orient and form the slurry ejected from the belt opening.

The conditions of projection given in the left-hand column of **Table 3** can be changed as desired by adequately setting the corresponding items in the right-hand column: it is possible to optimally change the speed and the sectional size of the slurry flux (part (a) of Fig. 9) to obtain a desired rate of deposition on the surface to repair by changing the specifications, the setting and the operation of the components of the device (part (b)).

5. Application to Cold Repair

Around the continuous rapid mixing/kneading and projecting unit explained above, a system for automatic ladle refractory repair in cold has been configured by combining the following: (1) constant feeders for the dry material, addition water and compressed air; (2) a system for position control (rotating, lifting/lowering, tilting) of the mixing, kneading and projecting machine; and (3) mechanisms to transport, position and support these units and set them in position in a vessel to repair. As seen in **Table 4**, this system unifies three processes hitherto carried out separately from each other into one continuous process.

5.1 Equipment for field trial

A prototype system was constructed for verification of practical workability and repair durability on commercial production facilities of different steelworks of the company. The test system shown in **Fig. 10** was meant to be set on the ladle bottom; another system to sit on the ladle rim was also constructed. Because the quality of the refractory formed on the repair object was of the highest importance at the trials, simplified mechanisms were used for the material supply and other components of the test systems.

5.2 Automatic refractory repair

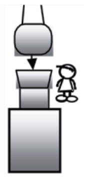
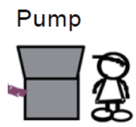
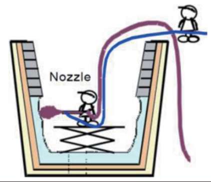
The developed machine combining the preparation and projection of refractory mixture has proved capable of forming a refractory layer of a desired thickness at a desired position by vertically moving, turning and tilting it. The thickness of the deposited refractory layer can be changed as required by adequately controlling the turning rate of the projection and the vertical speed of the equipment in combination with each other. Automatic refractory repair to obtain a layer of desired dimensions is possible by programming the equipment movement based on the above.

5.3 Examples of commercial QMS systems

(1) Suspended, centrally positioned type

Figure 11 shows a QMS system commercially used at Muroran Works. The system equipment is brought on a transfer car to above a ladle in a pit and lowered to inside it. There, it turns, tilts and

Table 4 Processes comparison

Process	Mixing	Transporting	Spraying
Conventional	Mixer	Pump	Nozzle
			
New	**Continuous quick mixing (QMS)**		
	Dispersion & mixing	Shortest transportation	Air-less projection
			

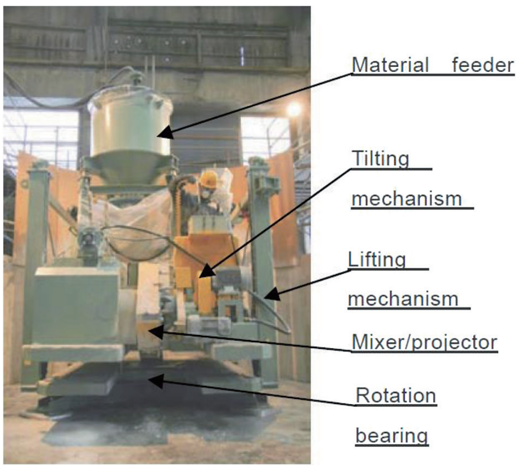


Fig. 10 Prototype system

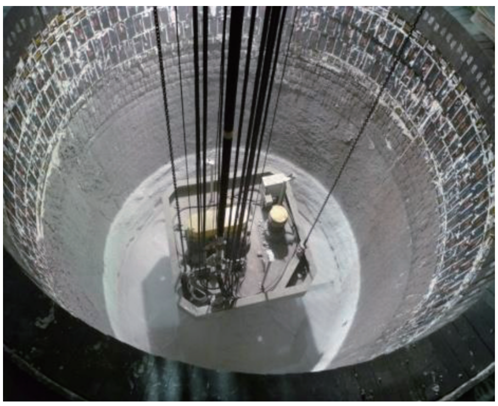


Fig. 11 Commercial QMS at work

moves vertically to form refractory layers of desired dimensions at desired positions of the ladle. To simplify the suspension mechanism, the equipment is hung by three wires, and the mixing and projecting system is tilted and turned as required by changing their

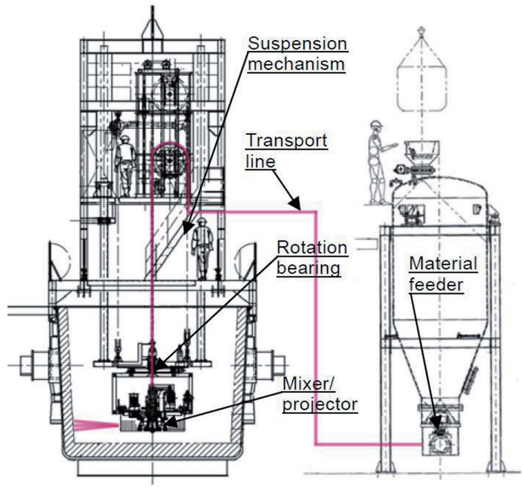


Fig. 12 Commercial QMS for large ladle

lengths.

The dry material is discharged from a bin at desired rates through a remotely controlled feeder equipped with a load cell, and then transferred to the QMS unit by flow-regulated air. Water is added to the material at prescribed rates. Then the material and the water are mixed in the rapid continuous mixer/kneader, and the mixture is projected to the ladle lining portion to repair. All the repair work process advances automatically following previously programmed attitude control patterns for lifting, tilting and rotating the flux of the mixture.

(2) Eccentrically positioned type

Figure 12 shows another QMS system used at Oita Works; the equipment is supported on the rim of the ladle to repair, but the system configuration and the process flow are the same as those of the suspended type. A principal difference is that the mixing, kneading and projecting unit is installed eccentrically on a turn table supported by a large-diameter bearing for ease of repairing large-diameter ladles, and is tilted on the table by means of a link mechanism. The system is equipped with a large capacity bin for the dry material for

10 t for continuous operation.

6. Application to Hot Repair

6.1 Required functions

The material properties required for hot repair are basically the same as those for cold repair listed in Table 2. Since the ease of operation is more important for hot repair, the mixing/kneading function is separated from the projection, and is provided in the middle of the refractory feeding line to maintain good workability and obtain high durability of the deposited refractory layer.

6.2 Issues regarding continuous mixer/kneader

In consideration of the above requirements, a rapid mixer/kneader capable of continuously preparing refractory material is incorporated in a conventional dry spraying system aiming at obtaining slurry of (1) low moisture, (2) closely packed structure, (3) good adhesion to the surface to repair, (4) high durability and (5) low dust emission. For good operability essential for hot repair, pneumatic conveying was selected for the transfer of the slurry to the spray nozzle in appreciation of its operation as easy as the dry spraying method.

6.3 Equipment system for hot repair

6.3.1 Modification to mixer/kneader

Figure 13 shows the construction of the mixer/kneader for hot repair. The dispersion and the mixing and kneading functions, which are borne by the inner rotor in the case of cold repair, are transferred to the inner surface of the stationary outer cylinder. Water is added to the dry material immediately before the entry to the mixer/kneader, and once in the machine (1) it is beaten by the kneading pins on the surface of the rotor turning at 1500 rpm, faster than that of the mixer/kneader for cold repair, to apply acceleration more than two orders of magnitude larger than that by conventional method to impose large shear force exceeding the coagulation force of the fine powder, (2) thrown onto the inner surface of the outer cylinder by the centrifugal force of the rotating pins, and moves downward while being sheared by the pins, (3) collected in the lower cone, and transferred pneumatically through the hose to the spraying nozzle. A supplementary stirring mechanism is provided in the collecting cone to help the discharge of the slurry.

6.3.2 Configuration of hot spraying system

As shown in **Fig. 14**, the hot refractory repair system, called H-QMI, consists of (1) a constant feeder for the dry material, (2) a transfer line for the dry material in powder, (3) a mist water injector to pulverize water with compressed air to facilitate wetting of the dry material in powder,[3] (4) a rapid continuous mixer/kneader, (5) a transfer line for the mixed slurry, and (6) a spray nozzle. The system has a capacity for 100 kg/min, and the water addition is less than that in conventional mixing methods by 20 to 30%. **Figure 15** shows a mobile H-QMI system of Muroran Works for repairing the lining of converters, and **Fig. 16** a scene during repair work by the system and the appearance of the repaired part.

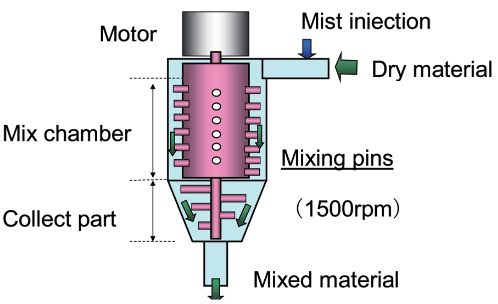


Fig. 13 Mixing mechanism of H-QMI

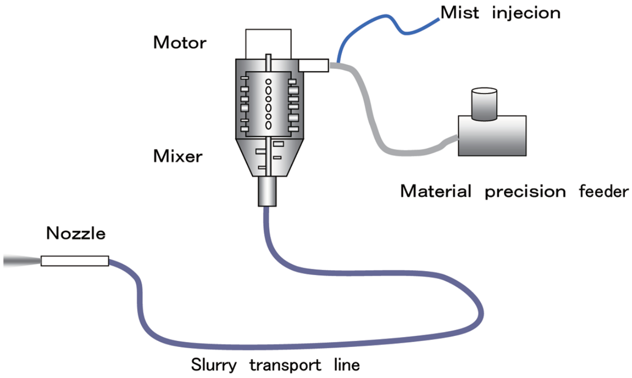


Fig. 14 System for H-QMI

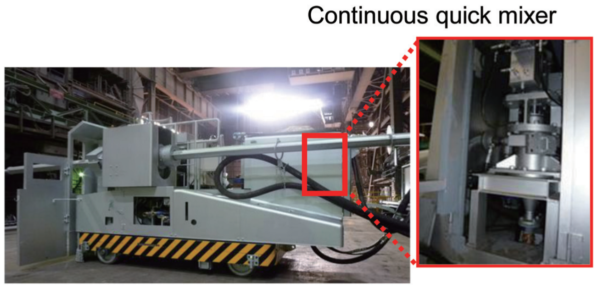


Fig. 15 Gunning machine equipped with H-QMI

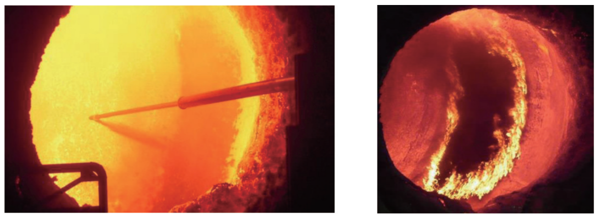


Fig. 16 Operational condition of H-QMI

A significant difference of H-QMI from conventional methods is that the sprayed material is thoroughly kneaded and the layer deposited on the surface is so thick that the combustion of tar in the sprayed material does not last long and the flame is seen only along the periphery of the deposited layer.

7. System Design for High Reliability

Since the process of QMS and H-QMI is continuous, fluctuations of material feed and water injection amount directly and adversely affect stable operation of the system, and thus system design to secure the stability of these parameters is essential.

7.1 Accurate feeding of material and utilities

Emphasis was placed on the following points in the selection of the system components:

(1) High accuracy of the material feeder: a mechanism not affected by back pressure.

(2) Homogeneous water addition: dispersion of water by mist spray.

(3) Stable air blow for pneumatic material transfer: a compressor and a constant flow valve excusive for each of the transfer lines.

The transfer line must be kept under continuous control to prevent clogging and other troubles, and a weigher is provided for the material bin for this purpose. In addition, the operation parameters, which were set conventionally by individual operators at their own discretion, are recorded automatically so that they can be referred to in the event of an accident or trouble.

7.2 Measures against wear of transfer lines

Since the system deals with highly abrasive refractory powder flowing at high speed, measures against wear must be taken at the following positions to secure stable operation for long periods:

(1) Bent portions of the transfer lines.
(2) Components of the mixer/kneader subjected to impact especially the pins and the blades (use of wear-resistant materials).
(3) The sealing mechanisms for the high-speed rotating parts of the mixer/kneader.

8. Closing

The development of the rapid continuous mixer/kneader for refractory powder has changed refractory repair work, which was divided into separate and labor-intensive processes, into a continuously combined and automated process. As a result, conventional problems of poor durability of deposited refractory have been greatly enhanced, and the tough work in a harsh environment significantly improved. At present, two QMS systems (for cold repair) and nine H-QMI systems (for hot repair) are commercially used at different steelworks in Japan.

Acknowledgement

Krosaki Harima Corporation worked with Nippon Steel & Sumitomo Metal as the joint development partner for the present technology. The development team of the company headed from time to time by Messrs. Ebisawa, Tohya and Itoh greatly contributed to the present development. Teams of the company repeated laboratory tests as well as field tests on real furnaces and ladles at different steelworks for nearly two years.

Mr. Sakae Nakai and his team originated the initial idea for the developed system and extended substantial support in the design and manufacture of the core part, the mixing and kneading mechanism.

The authors would like to express their sincere gratitude to these people for their invaluable help.

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