NIPPON STEEL TECHNICAL REPORT No. 125 DECEMBER 2020

Technology

UDC 666 . 763 /. 764 : 669 . 184 . 2 : 658 . 581

Methods of Evaluating the Damage of Steelmaking Refractories

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Abstract

The refractory used in the iron manufacturing process is damaged by various factors during campaigns. In order to maintain and manage the furnace, checking of refractory is necessary and repair and exchange of refractory must be performed based on evaluation of the results. Therefore, evaluation methods are important to prevent problems before they occur, improve productivity and reduce refractory costs. This report introduces a laser profile meter at BOF, an observation camera at the RH degasser, and thermography at the ladle as evaluation methods installed at Nippon Steel Corporation.

1. Introduction

The diagnosis technology of refractories is the core technology that compatibly realizes at a high level the prevention of serious problems such as molten metal leak and/or fire leak, high operating ratio and the reduction of refractory cost. In recent years, the importance of the role of such technology continues to grow as iron-making equipment and reheating furnaces in hot rolling process are deteriorating, and the operating conditions for refractories in the steelmaking process are becoming harsher as more sophisticated-quality steel is produced. Nippon Steel Corporation has developed hot state observation technologies and has introduced and uses high accuracy and high efficiency measuring equipment. This report describes examples of the utilization of refractory diagnosis technologies in the steelmaking process.

2. Outline of Diagnosis Technology

In the iron and steel making process, processing furnaces, transportation equipment and holding vessels are used, all of which are internally lined with refractories to handle high temperature hot iron metal, molten steel and steel rolling materials (such internally refractory-lined equipment is hereinafter collectively referred to as refractory-lined equipment). Refractories are damaged by a number of factors such as erosion by contact with slag, wear by molten steel, spalling by thermal shock and so forth. To maintain and manage refractory-lined equipment, it is necessary to inspect the refractories, grasp the state of damage and to repair or exchange refractories based on the result of diagnosis.

There are two types of refractory inspection: one is the offline inspection in which the target equipment is inspected in a resting condition and the other is the online inspection in which the target refractory-lined equipment is inspected in operation. **Figure 1** shows an example of the flow of management of refractory-lined equipment. In the offline inspection, as the refractory-lined equipment is cooled down and a diagnosis in close proximity becomes

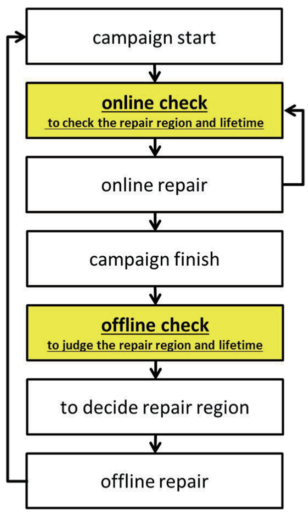

Fig. 1 Campaign flow of furnace

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possible, the state of damages of refractories can be grasped more precisely through the investigation of damages, actual measurement and the profile meter measurement of the remaining thickness during refractory dismantling. In the online inspection on the other hand, although a diagnosis as precise as that of the offline inspection is difficult, it is possible to capture the sudden falling and/or the abnormal erosion of refractories during operation, and the online inspection is indispensable to prevent accidents caused by wear of refractories. The online inspection generally relies on visual observation diagnosis. However, as the temperature of a furnace in operation is high, operator(s) access is limited. Therefore, various types of diagnosis equipment such as a profile meter, hot state observation camera (hereinafter referred to as an observation camera) and infrared ray thermography are applied.

There are two methods for diagnosing the state of the refractories in a furnace: a direct diagnosis method and an indirect diagnosis method based on the temperature of steel shell. The observation camera and the laser profile meter are the representative examples of the direct diagnosis method. As for the observation camera, since a TV camera is used for the observation of the furnace internal refractory conditions, the images so obtained are valid only for qualitative diagnosis. On the other hand, with the laser profile meter, the quantitative measurement of the remaining thickness of bricks is possible and therefore, from the result, the calculations of wear progress rate and remaining life are possible. Although it is easy to apply such direct diagnosis to refractory-lined equipment of open system types such as the BOF and ladle, the application thereof to closed system type refractory-lined equipment with a small throat such as a torpedo car and a vacuum degassing furnace (RH) becomes very difficult as the measuring equipment needs to be inserted through a small throat. For such refractory-lined equipment, the temperature of the steel shell of such equipment is measured by a radiation thermometer and/or by thermography, and the remaining refractory thickness is indirectly measured.

Examples of application of diagnostic technologies to the respective process in Nippon Steel are as follows (**Table 1**). As some of such equipment has been used for a few tens of years, it needs to be renewed systematically.

- In the ironmaking process
  - Hot-blast stove, coke-dry-quench equipment (CDQ): observation camera
- In the steelmaking process
  - Torpedo car (TPC): laser profile meter (PFM), thermography
  - BOF: fixed type laser profile meter (PFM)
  - RH: observation camera, thermography
  - Ladle: laser profile meter (PFM), thermography
- In the rolling process
  - Reheating furnace: observation camera, laser profile meter (PFM)

Table 1 Installation example of diagnostic equipment in Nippon Steel

Process	Furnace	Equipment
Ironmaking process	Hot-blast stove, CDQ	Observation camera
Steelmaking process	TPC	Profile meter, Thermography
	BOF	Profile meter
	RH	Observation camera, Thermography
	Ladle	Profile meter, Thermography
Rolling process	Reheating furnace	Observation camera, Profile meter

This report introduces examples of the utilization of the diagnosis technologies applied to BOF, RH and ladle in the steelmaking process.

3. Example of Utilization of Diagnosis Technology in Steelmaking Process

3.1 BOF

In a BOF, a key facility in the steelmaking process, scrap and auxiliary materials are charged to the hot iron metal from a blast furnace and pure oxygen is blown, and the compositions such as C, Si and P are adjusted accordingly. All steel grades produced in the blast furnace process are treated in this process. Accordingly, the BOF problems and/or shutdown due to maintenance are directly linked to the deterioration of the operating ratio of the entire steelworks. Since a BOF refractory campaign exceeds 4 000 charges at the maximum or six months in terms of the operation period, it is necessary to apply repairing depending on the state of damage and maintain the soundness of refractories during a campaign. Accordingly, the quantitative diagnosis of the remaining thickness of refractories and the appropriate repairing of the damage play important roles compatibly for the enhancement of the operating ratio and the reduction of refractory cost.

Conventionally, the management of the remaining thickness of refractories relied on the judgement made by visual inspection based on the skill of operator(s). In recent years, the laser profile meter(s) has been used for the quantitative measurement of the remaining thickness of refractories. In Nippon Steel, following the first employment for BOF in 1986[1], laser profile meters have been introduced to such refractory-lined equipment as torpedo cars and ladles.

In the measurement with the laser profile meter, the systems of measuring distance and position recognition are combined. A distance is measured by emitting a laser beam of a very short wave length onto the object of measurement from a revolving laser-emitting head and detecting the waveform of the received laser beam reflected on the surface of the object. The distance to the object is calculated by measuring the time difference between the emission timing and the reception timing. On the other hand, the position recognition of the laser profile meter is achieved by coordinate transformation with respect to the stationary objects such as the steel shell of the object of measurement and/or the surrounding structural members of the building, both taken as reference points. By the combinations of these measurements, the measurement of the remaining thickness of refractory-lined equipment is enabled.[2]

There are two types of laser profile meter: mobile type and fixed type. The comparison of these types is summarized in **Table 2**. The mobile type needs to be transferred by operator(s) from its storage site to a measurement site and its proximity to a furnace is restricted for safety reasons. Therefore, the scanning range per measurement is limited and a plurality of scans and a sufficient measurement time are required. This type is superior in that maintenance can be conducted regardless of the operation of the target refractory-lined equipment. Furthermore, since a profile meter can be used for a plurality of furnaces, the profile meter can be introduced at a relatively low cost. On the other hand, the fixed type travels to the measuring position automatically and as the position recognition is not required, measurement is conducted quickly. Furthermore, as the measuring position is fixed, this type has high measuring accuracy. In many cases, maintenance is conducted only when the target refractory-lined equipment is out of operation. Furthermore, as a laser profile meter is required per furnace and as a heat-resistant property is also required for its supporting structure, the cost of introducing the fixed type profile meter becomes high.

As an example of the introduction of a profile meter in Nippon Steel, an example of improving a mobile type profile meter applied to BOF is introduced.[3] **Figure 2** shows the appearance of a mobile type profile meter. A focus of the mobile type profile meter is to shorten the measuring time. To shorten the measuring time, (1) reduction of the number of profile measurements (scanning) and (2) shortening of the measurement of the position for position recognition were seriously considered. In the measurement by a profile meter, a plurality of scans are required and tilting of the furnace, closing and opening of the movable heat insulating board had to be conducted for each scanning of several times. Conventionally, to measure the entire inside of a furnace, since scanning had to be conducted at three different positions, namely a position right in front, left and right positions and at different tilting angles, therefore, it took 46 minutes for an entire measurement (**Fig. 3**).

Table 2 Comparison mobile and fixed profile meter

Mobile	Point	Fixed
○ Measure position move slightly each time.	Accuracy	◎ Measure position is fixed.
× 1. Scanning for position recognition is necessary. 2. Number of wear scan is more than fixed profile meter because profile meter cannot come closer to furnace.	Measurement time	◎ 1. Scanning for position recognition is unnecessary. 2. Number of wear scan is less than mobile profile meter because profile meter can come closer to furnace.
◎ Maintenance during operation time is possible.	Ease of maintenance	× Maintenance during operation time is impossible.
◎ One equipment can measure several furnace.	Cost	× 1. One equipment is needed for each furnace. 2. Heat resistance is needed.

Fig. 2 Appearance of mobile profile meter

Then, the “back scanning method (**Fig. 4**)” in which the plant building structural members are taken as reference points and the “instant positioning system (IPS)” in which the position is adjusted based on the profile of the furnace throat were introduced. Furthermore, measurement in close proximity to the furnace was realized by intensifying the heat resistant property and the employment of wireless remote controlling, and by expanding the range of each scanning thereby, the number of scannings was significantly reduced and the measurement time was reduced to 25 minutes. The wireless-remote control is very effective as a safety countermeasure against the fall of scull from the furnace top and/or from the furnace body. Due to the shortened measurement time, the number of measurements was increased and by suppressing the excessive repair, reduction of the amount of repairing material was achieved (**Fig. 5**).

For the BOF in the Oita Area of Kyushu Works, fixed type profile meters have been introduced.[4] As the position recognition is unnecessary for the fixed type profile meter, the measurement time re-

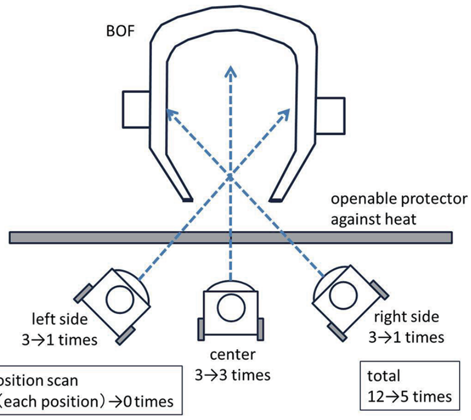

Fig. 3 Number of scanning about mobile profile meter measurement

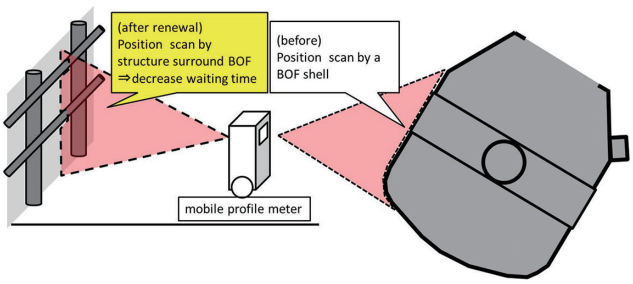

Fig. 4 Schematic view of back scanning method

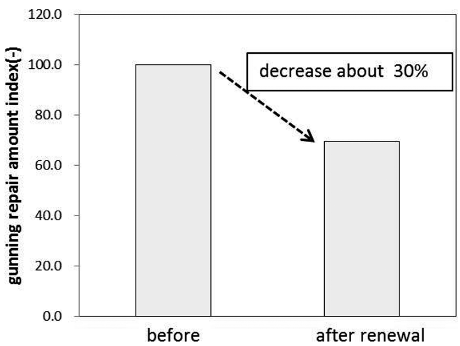

Fig. 5 Gunning repair amount index before and after renewal

Table 3 Comparison of measurement time

	Mobile	Fixed
Total measurement time	36 min	4 min
Position scan	20 min	0 min
Wear scan	16 min	4 min
Measurement frequency	Per 150 heats	Per 30 heats

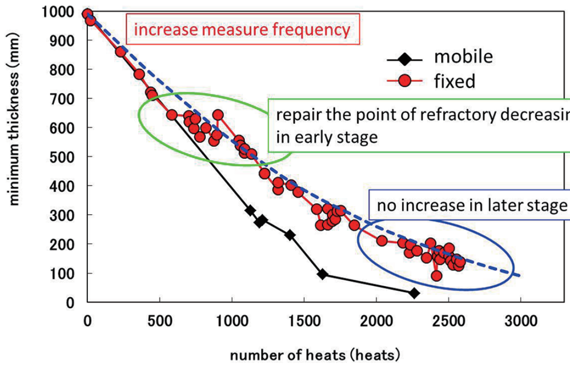

Fig. 6 Change of BOF brick thickness

quired for measuring the remaining thickness is shortened as compared with that of the mobile type profile meter, and therefore, the number of measurements is increased significantly (**Table 3**). Accordingly, the remaining thickness of refractories is grasped thoroughly and therefore, steel shell perforation problems, production impediment due to excessive repairing and increase in cost are prevented (**Fig. 6**).

Due to these improvements of the laser profile meter, the accuracy of the BOF management was enhanced significantly and the laser profile meter is contributing to the extension of the furnace life, enhancement of operation ratio and reduction of the repair amount. However, although the laser profile meter is a highly effective tool for measuring the remaining thickness of bricks, cautions are required as measurement of the laser shade region behind a scull is impossible. To solve this problem, the development of an inserted type laser profile meter and the application thereof to actual operation are desired.

3.2 RH

After the first step refining in BOF, the compositions of the molten steel are adjusted by vacuum degassing, decarburization and alloy metal addition in RH, which is one of the secondary refining equipment types indispensable for the production of high quality steel. An RH equipment consists of an RH vessel, lower RH vessel, snorkels and so forth, and the lower RH vessel and the snorkels are exchanged as necessary. For the judgement of such exchanges, it is necessary to diagnose the states of damages on the side wall of the lower RH vessel and the snorkels. Diagnosis of the state of damage with high accuracy and the exchange at an appropriate timing contribute to the enhancement of the operating ratio.

To conduct vacuum treatment, RH has high sealability and therefore, application of the laser profile meter as described earlier is difficult. Then, for the side wall of the lower RH vessel, a temperature monitoring system by means of thermography (referred to later) is used. On the other hand, conventionally, the insides of the snorkels and circulation tubes used to be inspected on a visual observation basis. However, as the observation from below the high temperature RH vessel had to be conducted, there was a safety problem of the deposit detached from the inside and/or the body of the furnace falling and directly hitting the observer. Therefore, remote-controlled monitoring equipment such as an industrial TV (ITV) was applied.

An example of such application in Nippon Steel is an observation camera applied to the RH snorkels.[5)] For the visual inspection of the RH snorkels, observation from below the RH vessel was necessary; however, there was a problem that the observation at a safe position does not provide a sufficient observation result. Therefore, an RH online observation camera equipment was developed with emphasis placed on the following three aspects: (1) remotely controlled automation of the observation equipment, (2) expansion of the measurable temperature range and (3) observation of full peripheries of the snorkel. In this equipment, the entire image of the snorkel is taken by internal observation cameras mounted on a turning arm and cameras for observing the snorkel outside wall, with all of the images being processed by a PC and displayed on the PC display in the operators' room (**Fig. 7**(a)). To observe the entire region of the inner sides of the snorkel, three cameras are installed per snorkel, while four cameras are installed to enable the observation of the entire external periphery (Fig. 7(b)). To protect the cameras from falling obstacles, a heat·dust protection cover and heat-resistant glass are used. The required time for the operation of the RH online observation equipment was set at about 70 seconds.

In **Fig. 8**, examples of images of the insides of the circulation tube and the snorkel taken by the RH online observation camera equipment are shown. Practically, by taking three images of a circulation tube and a snorkel, the states of the bottom refractory of the lower RH vessel bottom and the peripheral insides of the circulation tubes and the snorkels are confirmed. We assume that the circulation tube is a part of the bottom brick of the lower RH vessel and the abnormal wear of the top of the circulation tube indicates the wear of bottom brick of the lower RH vessel. Figure 8(a) is an image of the abnormal wear of the circulation tube that we consider shows the wear of the bottom brick and may develop a red-hot steel shell part and perforation. Figure 8(b) is an image of the crack of the refractory that causes detaching and fall of the refractory. Although with the conventional online visual inspection, identification of such abnormalities was very difficult, precise judgement has become possible by introducing the RH online observation camera equipment. With such an observation camera, qualitative diagnosis of the occurrence of cracks and/or abnormal brick failure is possible. On the other hand however, it is impossible to grasp the amount of wear of bricks quantitatively, leaving the problem of inability to manage the remaining thickness and/or judging the termination of the life.

3.3 Ladle

A ladle is used as a vessel for transporting high temperature molten objects such as hot iron metal and molten steel. In recent years, a ladle has been used as a reacting vessel for hot iron metal pretreatment by an impeller stirrer and/or for secondary refining by using a bubbling tuyer. Thus their operating conditions are becoming increasingly harsher. When an abnormality appears on the ladle refractories when transporting a hot molten object, the abnormality is linked directly to the leak of such high temperature molten object. By diagnosing the refractory damage precisely and by providing an appropriate repair based on the diagnosis, the prevention of molten metal leak and the reduction of cost are compatibly achieved. For the diagnosis of a ladle, measurement of the remaining thickness by using the aforementioned profile meter and monitoring of the steel shell temperature by thermography are conducted. Hereunder, an example of using thermography for a hot iron metal ladle is intro-

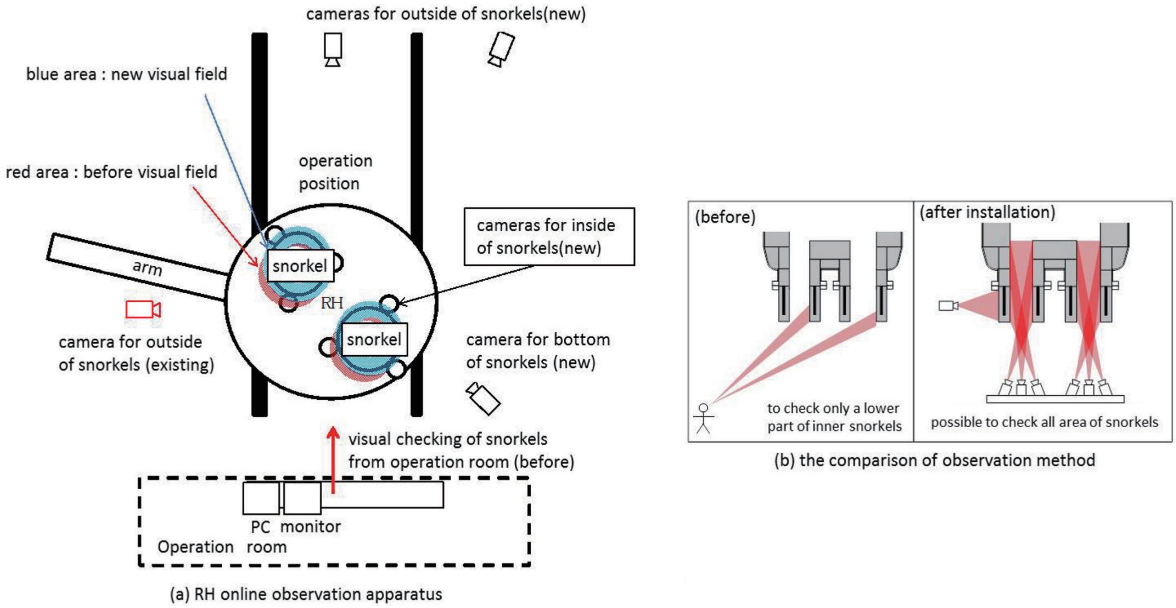

Fig. 7 Layout of online observation camera

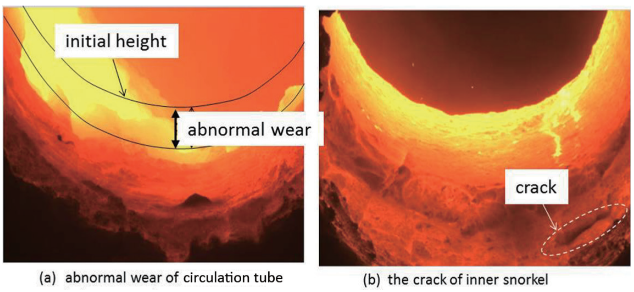

Fig. 8 Pictures of in RH snorkel by online observation camera

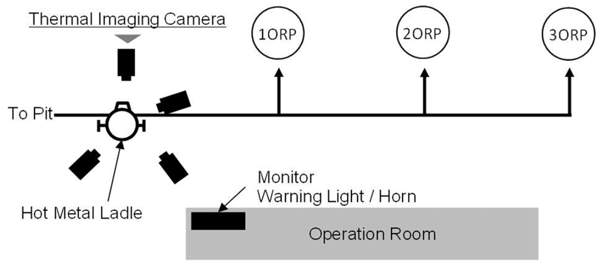

Fig. 9 Layout of observation equipment by infrared thermography

duced.[6)]

An infrared ray thermal imaging device (infrared ray thermography equipment) is equipment that graphically measures the distribution of the surface temperature of an object based on the strength of the infrared ray radiated by an object.[7)] In this method, the temperature distribution of an object can be measured remotely without contact. Presently, the infrared ray thermography is employed in diversified fields such as equipment diagnosis of infrastructures and plants, quality inspection of industrial products, exploration of the earth by artificial satellites and clinical diagnosis in the medical field.[8)]

Nippon Steel's first full scale monitoring of refractory-lined equipment by the infrared ray thermography was started in 1974 for the 1 300 ton metal mixer in the No. 2 steelmaking plant of the Muroran Works.[9)] In recent years, the resolution and the accuracy have been greatly improved, and with the commercialization of the noncooling type infrared ray sensor, small-sized (portable) type and low cost type thermography equipment have been realized. Thus presently, fixed type thermography is installed for almost all refractory-lined equipment in the steelmaking process and perforation accidents of refractory-lined equipment have been significantly reduced.

Infrared ray is an electromagnetic wave and is generated by any object at above absolute 0 degrees (0 K or −273°C) by the vibration and rotation of atoms and molecules. The wave length zone of infrared ray stays between 0.72 μm and about 1 000 μm, or in other terms, between the longest wave length of visible ray and the wave length of microwave.[10)]

The total energy radiated from a grey color body like the steel shell of refractory-lined equipment W[W/cm^2] is given by Expression (1) based on the Stefan-Boltzmann law.

$$W = \varepsilon \sigma T^4 \quad (1)$$

Where ε is the emissivity of a grey color body, σ[W/cm^{2}K^4] is the Stefan-Boltzmann constant and T[K] is the temperature of the grey color body. The infrared ray thermography detects the infrared ray energy of the object of measurement and determines the temperature of such.

For the actual hot iron metal ladle, infrared ray thermography equipment is installed near the route of transportation by a crane and laid out in such a way as to measure the entire steel shell of the hot iron metal ladle (**Fig. 9**). The thermography equipment is air-cooled as the internal temperature rises due to the heat radiated from the hot iron metal ladle.

The hot iron metal ladle internal lining layer consists of two layers of a permanent lining layer and a wear lining layer. As the wear liner refractory is worn and becomes thin, the overall thermal resistance deteriorates and the steel shell temperature rises. As the steel shell temperature reaches 400°C as the wear lining thickness is 50 mm of its allowable lowest limit, the steel shell temperature is monitored with this value taken as a threshold (**Fig. 10**). When the steel shell temperature exceeds the threshold, a system in the operators' room in front of the LD furnace issues a warning. With the introduc-

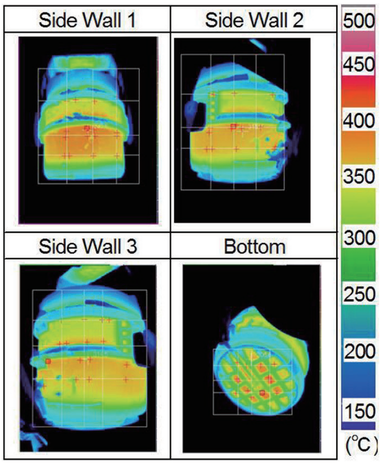

Fig. 10 Picture of infrared thermography on hot metal ladle

tion of the infrared ray thermography, extension of the life of the hot iron metal ladle could be determined and significant reduction of furnace material has been realized.

Although the steel shell temperature in a wide range can be measured simultaneously with the infrared ray thermography in this way, just like the steel shell temperature of refractory-lined equipment right after refractory repair is low, the temperature varies greatly depending on the states of heat accumulation and the state of internal deposits, leaving a problem of inability of quantitative management based on absolute temperature values. Therefore, a software is under development that consists of a logic that recognizes a hot spot based on the surrounding temperature differences and a logic that estimates the remaining thickness based on the consecutive processing of serial temperature change.

4. Conclusion

In the iron and steel making process, the diagnosis technologies of refractories are crucial in establishing compatibly the prevention of problems such as hot iron metal leak and/or molten steel leak, stabilization of production equipment and cost reduction. This report described the utilization examples of the refractory diagnosis technologies in BOF, RH and ladle in the steelmaking process that handle high temperature molten objects. These diagnosis technologies are effective tools in managing the refractory-lined equipment, despite implying specific problems to be solved. Hereafter, we will promote the technical development from hardware and software aspects. It is important to enhance the management accuracies of the refractory-lined equipment by applying such developed technologies to actual equipment.

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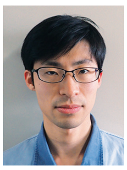
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