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Development of Repair Apparatus for Coking Chamber Walls of Coke Ovens

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Abstract

The bricks composing coke oven batteries deteriorate over long years of operation. Nippon Steel & Sumitomo Metal Corporation has developed the DOctor of Coke ovens (DOC) and used it for diagnosing the conditions of coking chamber walls of many batteries and repairing their damaged portions. New functions have been incorporated to DOC recently to repair damaged bricks near the chamber bottom and through holes, which were difficult for the old type DOC to repair.

1. Introduction

Most coke oven batteries now in operation in Japan were built during the high economic growth period of the 1960s and 70s, and many of them have worked for more than 40 years. The oven structure degrades during long operation, leading to decrease in production capacity and energy efficiency. Repair of coke ovens, however, is very costly; on the other hand, the personnel experienced in the laying work of special bricks for the ovens are now aged and in short supply. For this reason, extendinzg the service life of existing coke ovens is a difficult task common to all steel makers and coke producers in the country.

Facing this problem, Nippon Steel & Sumitomo Metal Corporation developed an apparatus for diagnosing and repairing the walls of coking chambers, named the DOctor of Coke ovens (DOC), and applied it commercially to all its coke ovens.[1)] The facility is capable of quantitatively evaluating the deterioration of coking chamber walls and repairing damaged portions even at the center of the chamber accurately by hot spraying, which is impossible by manual work.

The functions and capabilities of DOC have been improved over the last years such that it is now possible to repair damaged wall parts near the bottom and through holes, which the old type DOC could not. This paper presents the development of the functions and facilities newly added to DOC for the purpose.

2. Conditions of Aged Coking Chamber Walls

Coke ovens are composed of silica bricks. When cooled to 600°C or below, these bricks undergo rapid and significant shrinkage, and the whole oven structure is weakened. For this reason, coke oven batteries are kept in operation at temperatures over 1 000°C throughout its service period of more than 40 years. The walls of coking chambers are subject to repeated thermal and mechanical stresses at the coal charging and coke discharging in everyday operation, and as a result, the brick surfaces spall, crack, or wear. In addition, carbon often deposits on the wall surfaces forming protrusions, and the surfaces become rugged over years of operation, which increases the resistance to the coke discharging (pushing), often leading to troubles such as pushing failures. What is more, higher force required for coke pushing leads to an increase in the lateral pressure of coke on the chamber walls, possibly causing falling off of bricks. **Figure 1** illustrates typical examples of such troubles. Wall thinning results from surface loss of bricks, originally 100 mm in thickness, often covering several bricks, and sometimes as deep as 50 mm. A vertical through crack forms as a result of vertical

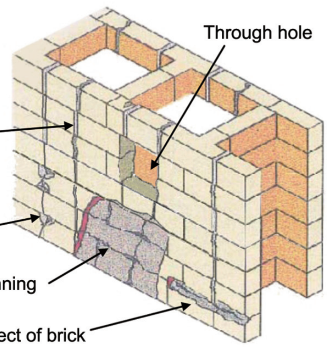

Fig. 1 Typical damage patterns of the chamber wall

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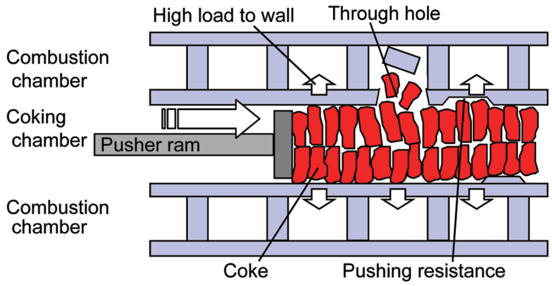

Fig. 2 Formation mechanism of broken hole

cracking of bricks, which are laid in a staggered manner tier by tier, and breakage of vertical joints connecting together in the chamber height direction; it decreases the structural strength of the oven significantly as it grows. Brick corners along cracks and broken joints, either horizontal or vertical, are likely to fall off. Recently, brick corner breakages were found to develop along horizontal joints of many coke ovens, especially in the chamber wall portions near the bottom. Through holes form at thinned or cracked wall portions when bricks fall off under lateral force of coke pushing exceeding the strength of the parts. **Figure 2** illustrates how such a hole forms. Through holes, when left unattended, constitute a serious damage, rendering the coking chamber out of use, and they tend to occur more often as the ovens age.

3. Outlines of DOC

To decrease the resistance at the pushing operation, it is essential to quantitatively measure the positions and depths of wall depressions due to brick thinning and missing corners and filling them to make the wall surface flat. However, a coking chamber is a large and narrow space, approximately 6 m in height, 16 m in length, and 0.4 m in width and is always heated to 1 000°C or above. Naturally, it is difficult, or utterly impossible, to look into it from an end, evaluate damaged portions with the unaided eye, and fill the depressions flat by manually inserting a long hot spraying gun that can reach the positions requiring repair.

In consideration of all these, Nippon Steel & Sumitomo Metal has developed DOC as a machine that can diagnose and repair damaged parts of coking chamber walls, and has commercially used it for all its coke ovens. DOC is capable of accurately measuring protrusions and depressions of the entire chamber walls in hot and filling depressions by hot spraying to make the surface flat. **Figure 3**[1)] schematically shows its configuration.

DOC comprises a diagnosis system and a hot spraying system. The former identifies wall cracks and measures wall distortions and other dimensional anomalies by observing the whole chamber wall area using a high-resolution CCD camera and measures the chamber width in the height direction using a laser range finder. The positions of portions found defective and the depth of the depression are expressed numerically in a three-dimensional coordinate system. **Figure 4**[1)] shows an example of the diagnosis result of a chamber wall by COD. The map shows local wall thinning (depressions) and carbon deposits scattered in wide areas as well as many vertical through cracks.

The latter repairs damaged wall portions by hot spraying based on the information given by the former. The part of the system that goes into the coking chamber is covered with heat-insulating materials and cooled with water jackets; it can stay and work in a coking

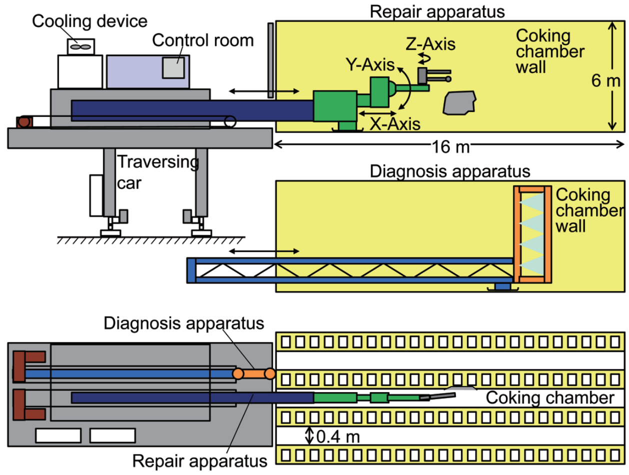

Fig. 3 Schematic diagram of DOC[1)]

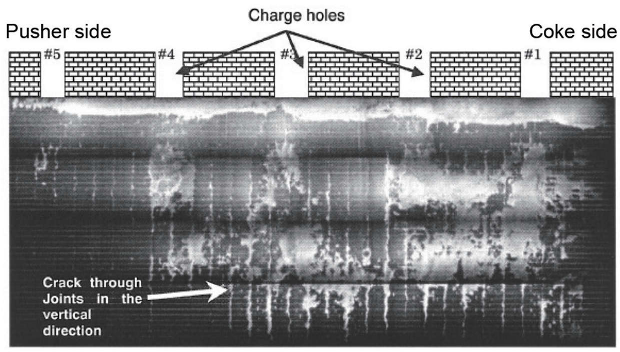

Fig. 4 Example of the diagnosis of the wall by DOC[1)]

chamber for more than 2 h continuously. Once in a chamber, it determines the exact positions of damaged parts, burns carbon deposited on the walls, defines the movement (route) of the hot spraying nozzle to fill a depression and fills it automatically without requiring intervention from the control room. The flame gunning machine for hot spraying was developed in house,[2)] has a capacity to spray about 20 kg/h of high-purity silica refractory. During the flight from the spray nozzle to the wall surface in a high-temperature flame, the refractory melts and then sticks to the target surface to form the filler. The spraying nozzle and the laser profile gauge, movably mounted at the head end of the horizontal arm, are precisely positioned by a three-axle, serial-link manipulator as desired about the x-, y- and z-axes given in Fig. 3. The movement in the chamber length direction (along the x-axis) is in a straight-line stroke of about 2 m, and those in the height and width directions (about the y- and z-axes) are rotational, and in filling a depression with different local depths to form a flat surface, the rate of filling per area is controlled by changing the nozzle moving speed. Since a coking chamber is large in the length direction and narrow in the width, the rigidity of the horizontal arm is limited owing to dimensional restrictions, but this problem is taken care of by a vertical leg that is provided near the head end and extends and shrinks at high speeds at a prescribed stroke to support the arm against the chamber bottom: it enables high-precision repair by spraying at any position of a chamber wall. The rotation angle about the z-axis is very limited because of the narrow chamber width, but this limited movement is advantageous for keeping the spraying distance constant and obtaining a deposited layer of high quality. The high-accuracy positioning of the nozzle explained above is a fundamental difference from the conventional spraying repair, whereby a spray gun several meters long was held and manipulated manually from an end of a coking chamber. Thanks to the automatic remote operation from the control room, the work environment and safety of the operators have been greatly improved.

4. Development of Repairing Apparatus for Chamber Walls near Bottom

4.1 Types of wall damage near bottom

The conventional types of DOC was capable of repairing damaged parts in most of the wall area, but because of the manner of mounting the nozzle on the extendable arm and parts of the equipment possibly interfering with the bottom, it was impossible to aim the spray nozzle correctly to the wall portions near the bottom. Recently, however, in some coke ovens, brick corners were found to have fallen off locally in the wall areas near the bottom as shown in **Fig. 5**. This type of damage is considered likely to occur in such portions because of the weight of the wall and the lateral force during coke pushing being large there. It is necessary to repair this type of damage because, if left unattended, it will lead to increased resistance to pushing and, possibly, collapse of the wall.

There are two varieties to the type of damage: one is as shown in part (a) of Fig. 5, wherein the corners of the bricks immediately below the joint about 150 mm above the bottom (the second tier) are missing; and the other in part (b), wherein the bricks of the second tier are thinned significantly nearly in the entire height. In either of the cases, the bricks of the third and upper tiers are comparatively sound. Different from the wears in higher positions, where depressions have gentle slopes and cover rather large areas, the slope at the joint between the second and the third tiers is nearly in right angles or in a steep gradient, and such depressions of missing edges extend horizontally in considerable lengths.[3)]

4.2 Functions required for repair of wall portions near bottom

4.2.1 Mechanism for preventing collision with chamber bottom

When the slope of a depression is steep, sprayed material may fail to fill the depression and form a mound near it unless the spray nozzle is trained very accurately, and it is necessary to control the nozzle correctly and precisely. In view of this, the development team considered it effective to spray the material only to the bricks of the second tier from the bottom by guiding the nozzle in parallel to horizontal joints. In addition, it was necessary to take measures against the collision of the apparatus with the chamber bottom, which occurs mainly in the following situations:

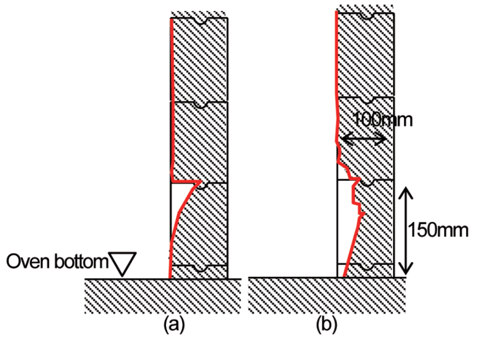

Fig. 5 Typical wall damage patterns close to bottom

(1) Collision with lumps of coke remaining in chamber

Before repair work by hot spray, the chamber bottom is cleaned, and few coke lumps remain there, but there is yet the possibility of the repairing apparatus hitting some left on the bottom. As countermeasures, a camera and a chamber bottom shape sensor (explained later herein) were newly provided at the head end of the machine to detect objects protruding from the bottom in order to so adjust the machine attitude that the lowest part of the machine would not hit them.

(2) Collision with bottom due to machine careening

The alignment of the rails for the coke pusher, with which the carriage for DOC shares the rails or on which DOC is mounted, and the level of coke oven battery change during long years of operation, and as a result, the positions of the support points of DOC on its carriage relative to the oven differ from chamber to chamber, and the machine is tilted slightly. The angle of tilting is roughly 1° at the largest, but as the spray nozzle moves along the x-axis by 2 m, the change in its vertical position amounts to 30 mm or more, which is a considerable aberration. To prevent this from occurring, the following two functions have been newly introduced:

(i) Chamber bottom shape sensing

A dislocation sensor is provided at the lower side of the head end of the repairing arm to measure the distance to the chamber bottom. This is to define the movement angle along the x-axis relative to the bottom face by measuring the distance along the 2-m stroke.

(ii) Vertical positioning of support rolls on DOC carriage

To make the said stroke along the x-axis parallel to the bottom face, the height of each support point of DOC on the carriage is made adjustable. This mechanism allows rapid movement along the x-axis in the entire stroke keeping the distance from the bottom constant, the minimum being 10 mm. This also makes it easier to move the nozzle parallel to horizontal brick joints. **Figure 6** schematically illustrates the support structure on the carriage.

4.2.2 Mechanism for rotating spray nozzle

The conventional type of DOC was designed to repair wall depressions covering a comparatively large area and having gentle slopes. For this end, the hot spray nozzle was mounted so as to proj-

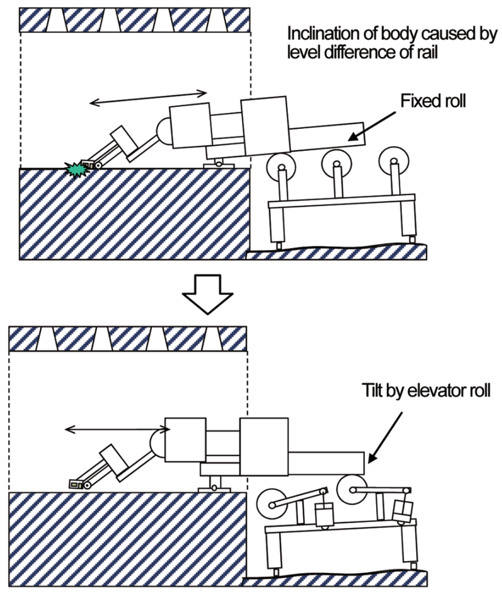

Fig. 6 Support mechanism for avoiding collision with chamber bottom

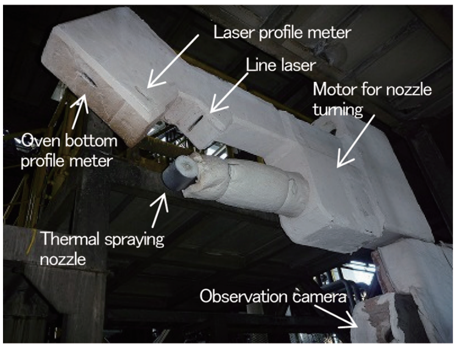

Fig. 7 Appearance of apparatus for repairing brick defects near chamber bottom

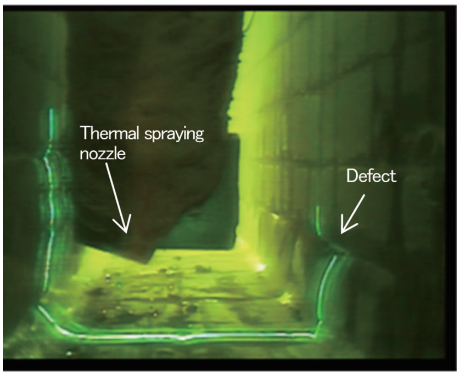

Fig. 8 Defect close to the oven bottom

ect the material perpendicularly to the wall surface, and using a nozzle 100 mm in outer diameter, it was impossible to spray the material to the wall portion roughly 50 mm from the bottom or below. To solve this problem, a new nozzle mount has been introduced to the new version of DOC so that the nozzle is tilted downwards by 10 to 20° to cover the lowest part of the walls. The downward nozzle angle can be changed as desired according to the shape of the depression to fill. **Figure 7** shows the appearance of the head of the new version DOC.

The photograph of **Fig. 8** was taken by a camera mounted near the head end of the machine arm; it shows a defect of the wall and the spraying nozzle. A line laser beam is projected in right angles to the wall surface to make the sectional shape of the depression easily visible in green curves.

4.3 Application example

Figure 9 shows an example where the new DOC was used for repairing a coking chamber wall. Part (a) shows contours of the wall surface in question before the repair, and part (b) after it; the portions in dark blue near the bottom in part (a) are depressions extending below a horizontal joint 150 mm from the bottom. Part (c) compares the horizontal profiles of the wall at the A-B section before and after the repair: the depressions 40 to 50 mm in depth were filled by the thermal spraying operation to form a substantially smooth surface. This type of DOC was applied to coke oven batteries that had long, horizontal and intermittent depressions at the lowest-most portions of chamber walls, and most of the defects were remedied in two years after the introduction. Thus, the precise and efficient repair ability of the new apparatus have proved effective at recovering the soundness of coking chamber walls.

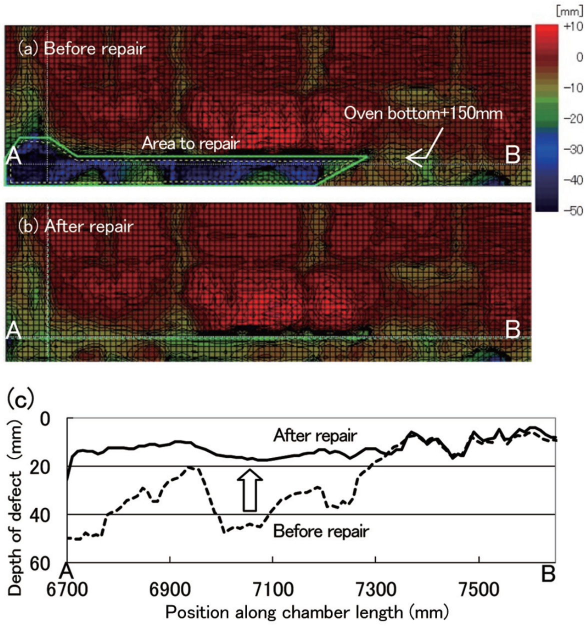

Fig. 9 Surface profile of the repaired part

5. Development of Repairing Apparatus for Through Holes

5.1 Methods of closing through holes

5.1.1 Problems with conventional methods of repair

A hole through a coking chamber wall significantly hinders the coke production of the chamber and, since coal charged into the chamber flows through it into the combustion chamber, the latter and the regenerator beneath are clogged, leading to insufficient coking in related coking chambers. At present, a through hole near the center of a coking chamber is repaired by putting the combustion chambers on both sides out of operation, leaving them to cool to room temperature, having personnel reach the place to remove embrittled bricks around the hole, laying bricks with mortar to close the hole by human work, and then heat the cooled oven section to the normal operating temperature. By this method, however, the oven section has to be cooled to allow human work inside and then heated to the normal operating temperature, the silica bricks inevitably transform and crack under rapid volume change, and the damage to the oven structure expands to otherwise sound portions. In other words, repair of a through hole in one chamber wall is likely to shorten the service life of the entire coke oven. The repair significantly and adversely affects the production since the cooling and reheating of the oven section takes time, and the adjacent coking chambers are also adversely affected during the period. In consideration of all these, development work was launched for a new version of DOC capable of closing holes through chamber walls in hot.

5.1.2 Problems to solve for closing through holes using DOC

Since DOC sprays refractory material together with a high-temperature flame perpendicularly to the wall plane, when it is used for closing a hole through a wall, the sprayed material goes through the hole into the combustion chamber. On the other hand, when it is used so as to deposit the sprayed material on the inner face of the hole to close, a considerable part of the material is likely to deposit along the rim of the hole forming protrusions toward the chamber inside; therefore, this method is not practical. Thus, preventing the sprayed material from blowing through to the combustion chamber is essential for the repair of through holes. In the meantime, it has been proved through tests that the blow through does not take place when the opening is about 20 mm wide or smaller.

In consideration of this, the authors and their team worked out a method whereby a piece of brick a little smaller than the size of the hole in question is inserted in it, and the thermal spray is applied to the gap between the plugging piece and the inner surface of the hole; in this case, the gap around the plugging piece is roughly 10 mm wide. **Figure 10** schematically illustrates the conceived method.

5.1.3 Process steps to close through holes by developed method

The process steps for closing holes through coking chamber walls, which has been established through the development studies, are explained below in more detail referring to the photographs in **Fig. 11**, which were taken during tests.

(1) Measurement of hole

In the first place, DOC is inserted into the coking chamber in question to measure the shape and size of the through hole to close using a laser profile gauge.

(2) Forming plugging brick piece

A piece of brick is cut to the measured shape and size of the hole. Here the outer contour of the piece must be smaller than the inner contour of the hole so that a gap about 10 mm wide is left between it and the hole. In addition, for holding it using a mechanical hand, two holes are drilled into it.

(3) Holding plugging piece

The plugging piece is held by inserting two fingers (bars) of the mechanical hand into the drilled holes.

(4) Inserting plugging piece into hole

The plugging piece is brought into the chamber and inserted into the hole to close. Here, based on the relative position of DOC to the chamber wall measured real time with the laser profile gauge, the piece is inserted to a prescribed depth from the wall surface and held there.

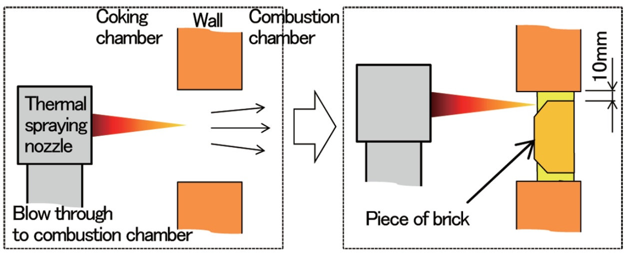

Fig. 10 Method for repairing broken hole by thermal spray

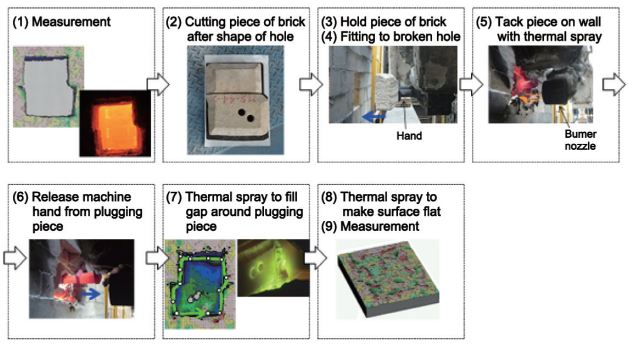

Fig. 11 Process of repairing broken hole

(5) Temporary fitting of plugging piece to hole

To prevent the plugging piece from falling during the subsequent work, it is temporarily fitted to the hole inside by applying the thermal spray to a part of the gap around it, while it is held by the mechanical hand.

(6) Detaching mechanical hand from plugging piece

The fingers of the machine hand is pulled out of the finger holes of the plugging piece by moving the hand away in right angles to the wall face.

(7) Thermal spraying to fill gap around plugging piece

The gap around the plugging piece is measured for a second time, and based on the measurement, the path of the spray nozzle movement to fill the gap around the piece is defined, and then, following the path, the gap is filled with the refractory material by automatic thermal spray. By this, the opening between the coking and the combustion chambers is closed, and the plugging piece is firmly bonded to the wall portion to secure the strength to withstand the lateral force of coke pushing.

(8) Filling up entire hole by thermal spraying

The spray operation is continued to fill up the depression of the hole to make the surface flat. This work step is the same as the repair of depressions explained in Section 3.

(9) Wall profile measurement after repair

Finally, the wall surface after the repair is measured to confirm its flatness.

5.2 Functions of through hole closing apparatus

5.2.1 Mechanism to insert plugging piece

Since a coking chamber is always kept at 1 000°C or higher, and its width is as small as 0.4 m, as mentioned earlier, and apparatuses meant to work in this environment must be thickly wrapped with heat-insulating coatings and water cooling jackets, the machine was designed to have a simple structure with as few movable parts as possible. While the spray nozzle manipulator of the prior type of DOC was movable about three axes (x, y and z), two axes or three seemed to be additionally required, at the beginning of the development studies, to set a plugging piece into place keeping its orientation. Rearranging the positions of the machine hand and the laser profile meter, however, addition of only one axis was found necessary for the required function; the additional axis, called the z'-axis, turned in the same direction as the z-axis and was mounted at the working end of an arm supported by it. **Figure 12** shows how a plugging piece is inserted by the mechanism: after the brick piece is positioned in front of the hole to close, it is moved at right angles to the wall plane into the hole to a prescribed depth by synchronized actuations of the four axes (w, y z and z'). The developed mechanism proved capable of placing the piece into place while maintaining the 10-mm gap around it.

5.2.2 Handling of plugging piece in hot

The plugging piece is held simply by two fingers (bars) of the machine hand inserted into two holes drilled into it. At the begging

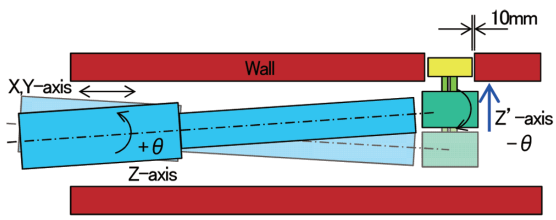

Fig. 12 Machine motion to fit plugging piece into hole to close

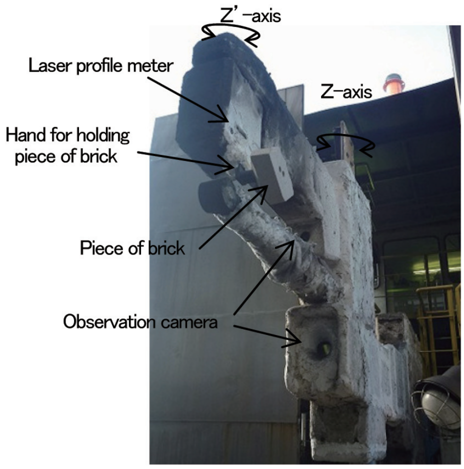

Fig. 13 Overview of the apparatus for repairing broken hole

of the development studies, various heat-resistant alloys were tried as the material of the fingers, but they deformed during the temporary fitting of the piece to the hole by flame spraying, and the piece tilted. Finally, a carbon-based material was selected for the part, which was redefined as a disposable, one-trip device.

Figure 13 shows the appearance of the apparatus for closing through holes; here, a plugging piece is held by the hand on the z'-axis at the head end of the machine.

5.2.3 Thermal spraying to gap around plugging piece

Originally, DOC was designed for repairing chamber wall depressions by brick thinning, and an inaccuracy in the training of the spray nozzle by 20 or 30 mm was not a serious problem. When it is used for filling a gap roughly 10 mm wide, however, missing a target by several millimeters is a serious problem, possibly leading to formation of uncalled-for protrusions at an otherwise sound wall surface, or imperfect closure of the hole allowing leakage of the gas from the coal into the combustion chamber, and thus precision positioning of the spray nozzle became essential. For this end, severer calibration was applied to every support/drive axis for the nozzle positioning, and a new program was formulated to enable spraying operation along the gap around a plugging piece.

5.3 Application example

Figure 14 shows a through hole of a real coke oven after being

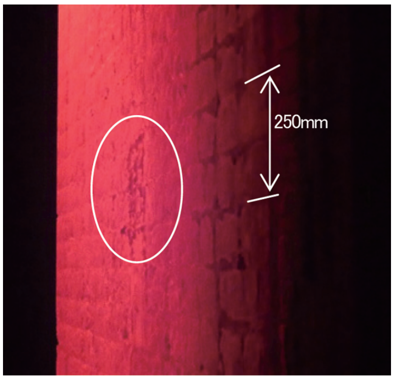

Fig. 14 Repaired broken hole

closed at a trial repair using the developed apparatus of DOC; here, the hole was originally caused by falling off of bricks in two tiers as shown in Fig. 11. The wall surface was finished to a roughness of ±10 mm, approximately. After two years of the closure of the hole, the wall is standing firmly and keeping enough strength, which evidences the effectiveness of the method of closing holes in hot.

6. Closing

Nippon Steel & Sumitomo Metal developed and commercially used DOC at all its coke ovens to numerically diagnose the conditions of coking chamber walls and repair defects in hot by thermal spraying. Some new features have been added to the machine to render it capable of repairing the wall portions close to the bottom and closing holes through chamber walls due to falling off of bricks. The repair of the portions close to the bottom has been made possible by devising a mechanism to prevent the machine from colliding with the bottom and the like. Closing of through holes in hot has been made practicable by a mechanism and a machine hand to insert a plugging piece of brick into the hole to close. Further development of equipment technologies for hot repair of coke ovens is being pursued for their stable operation and extension of their service life.

References

1) Sakaida et al.: Shinnittetsu Giho. (384), 63 (2006)
2) Kasai et al.: Shinnittetsu Giho. (388), 54 (2008)
3) Masaki et al.: CAMP-ISIJ. 22, 786 (2009)

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