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Development of Diagnosis/Repair Apparatus for Coke Oven Chamber Wall

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Abstract

As coke oven batteries have become gradually decrepit in recent years, the "service life extension technology for coke ovens" has become an important issue. In the past, the operator inspected the battery visually upon occurrence of abnormalities, such as hard pushing, during the coking operation and the damaged portion was repaired based on the information obtained from the visual inspection. As the frequency of hard pushing and through hole formation has increased in recent years, effective repairs by the conventional method have become difficult. Accordingly, there has been a need for early detection of damaged wall and planned repairs based on the results of quantitative diagnosis. The present paper describes the high-accuracy oven wall diagnosis/repair apparatus developed to solve the problems described above.

1. Introduction

Some of the coke ovens now in operation at Nippon Steel Corporation are 41 years old (average age: 37). Since they are becoming somewhat superannuated in recent years, developing technology to extend their useful life has become an important issue. In the past, when a pushing failure or some other trouble occurred during coke oven operation, the operator used to visually inspect the coke oven in order to resolve the problem. Recently, as the loss of thickness, increased surface abrasiveness and spalling of oven wall bricks have become ever more conspicuous, the incidence of pushing failure and other problems which impede stable coke oven operation have been increasing. Under such circumstances, it has become increasingly difficult to repair the problematic coke ovens efficiently with conventional methods. Therefore, early detection and quantitative analysis of the damaged parts of oven walls to allow for planned repairs have been called for. This paper describes the highly accurate diagnostic and repair system we have developed for coke oven chamber walls to remedy the above problems.

2. Concept of Coke Oven Life

The types of damage suffered by coke ovens can be classified as shown in **Fig. 1**. Typical examples of damage to a coke oven are shown in **Fig. 2**. The parts of the coke oven that are most susceptible to damage are the coking chamber and combustion chamber. Damage to the combustion chamber can effectively be dealt with to a certain extent by means of an air blow from the bottom of the regenerator and removal of foreign matter from the oven top.

On the other hand, the coking chamber walls are subject to mechanical load and thermal load – repeated heating and cooling – in routine operation and hence, the damage to them gets steadily worse year by year. There are two major types of damage to the coking

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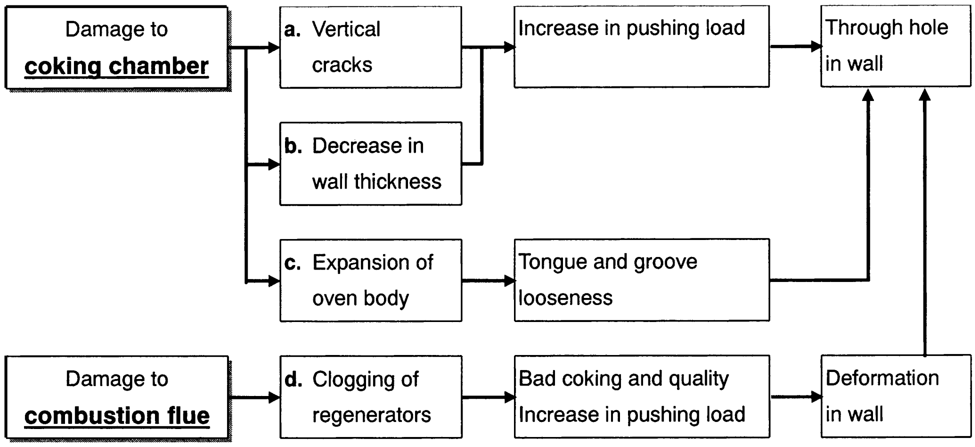

Fig. 1 Schematic flow of coke oven deterioration

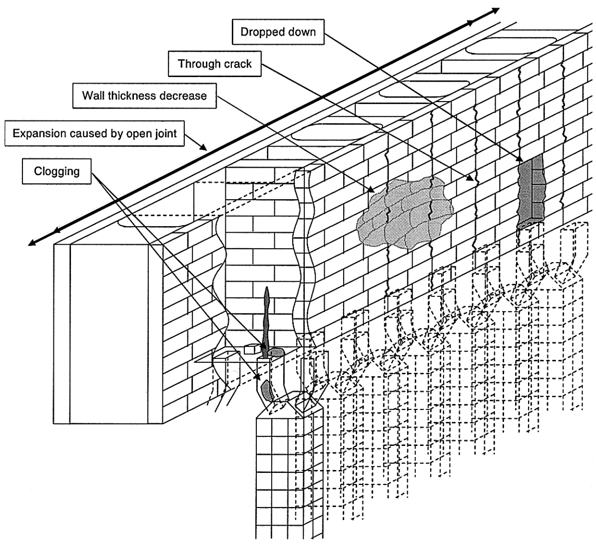

Fig. 2 Typical damage pattern of chamber brick

chamber walls. These are:
(1) Decrease in brick wall thickness

Carbon deposits on the rough surface of the wall caused by erosion of the brick and the loss of mortar over the many years of oven operation. As the carbon deposits fall off or separate from the wall, it peals off more of the disintegrating brick, causing further erosion of the brickwork.

(2) Occurrence and propagation of vertical through-cracks

Under the mechanical impact during the charging of coal and the thermal stress induced by the repeated heating and cooling, longitudinal cracks form which eventually reach the combustion chamber. As carbon gets into those cracks, the oven body expands.

At Nippon Steel Corporation, once a through-hole is made in the coke oven wall, the service life of that oven is assumed to have expired. At such time as the number of those coke ovens in a particular battery has increased to the point where the battery productivity is judged economically unsustainable, it is assumed that the service life of the battery has expired.

There are two major factors that govern the service life of a coke oven. One is the structural stability of the coking chamber walls, and the other is the load applied to the walls when coke is pushed out of the chamber. As the coke oven ages, the structural stability of the walls decreases while the load applied to the walls increases. Therefore, minimizing the decrease in structural stability and the increase in load with the lapse of time and shifting the intersection of the two curves (oven wall collapse point) to the right (delaying the onset of that point) as much as possible constitutes “technology for prolonging coke oven life”. Thus, it is considered that technology for prolonging coke oven life consists of the following two elements (**Fig. 3**).

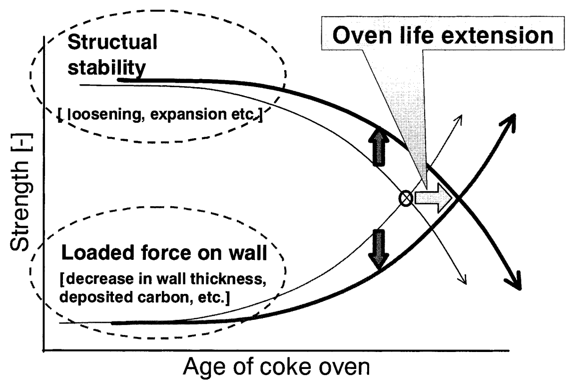

Fig. 3 Concept of the determining factor of coke oven service life

(1) Technology for retaining the structural stability of coke ovens
(2) Technology for reducing load applied to coking chamber walls

In the present study, focus is placed on developing a device for smoothing the surface of coking chamber walls in order to reduce the load applied to the chamber walls.

3. Objectives of Development of Coke Oven Chamber Diagnostic and Repair System

The conventional methods for determining the degree of damage and repairing damaged parts were dependent on visual inspections by oven operators and flame gunning by many workers. These are subject to a number of problems, such as inaccurate quantification in determining the degree of damage, the difficulty involved in evaluating the condition of the central part of the coking chamber, inaccurate surface finish and inadequate durability of parts repaired by flame gunning, heavy muscular labor under high temperatures, etc.

In order to solve the above problems, the following objectives were set in the present project.

(1) Quantitative measurement of oven wall irregularities
(2) Accurate determination of damaged part positions
(3) Speedy measurement of coking chamber side walls (within 5 minutes)
(4) Smooth, high-accuracy flame gunning to damaged surfaces (irregularities within 10 mm)
(5) Significant reduction of workload by automatic flame gunning.

4. Outline of Devices in Newly Developed System

Fig. 4 schematically shows the newly developed system for diagnosing and repairing coke oven chambers. **Table 1** shows basic specifications of the system, and **Photo 1** shows a general view of the system. This system has two sets of water-cooled probes similar in shape to the pusher ram, probe inserting devices and probe coolers mounted in parallel on a traversing car that runs on the pusher rails. The system consists of oven wall diagnostic equipment, which is provided with CCD cameras, laser rangefinders and their controls, and oven wall repair equipment, which is provided with a manipulator having a laser profile meter at the front end, a descaling device and flame gunning burners.

In order to diagnose a coke oven chamber, the system enters the oven, in which it makes a round trip in about four minutes while observing the side walls. Four special CCD cameras allow for high-resolution imaging of all walls of the coke oven chamber. In addition, three laser rangefinders permit measuring of oven widths at three different oven heights and obtaining profiles of oven wall deflections, large cracks, etc. If any part is judged to be damaged by

Table 1 Basic specifications

Diagnosis	
Chamber wall image	Liner CCD camera × 4 : Range 6 m × 15 m measurement of unevenness by light section method
Chamber width	Laser range finder × 3 : 3 stages × 15 m
Measuring time	4 min (back and forth)
Data processing	Contour map of the Chamber wall Damage information analysis system
Repair	
Evenness	±10 mm
Spray speed	40 kg/h

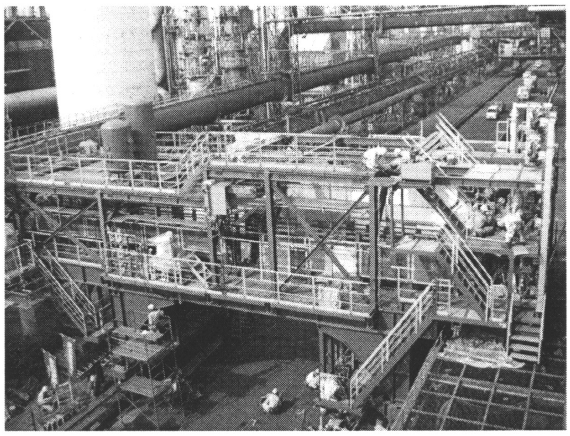

Photo 1 Overview of coking-chamber wall diagnosis and repair equipment

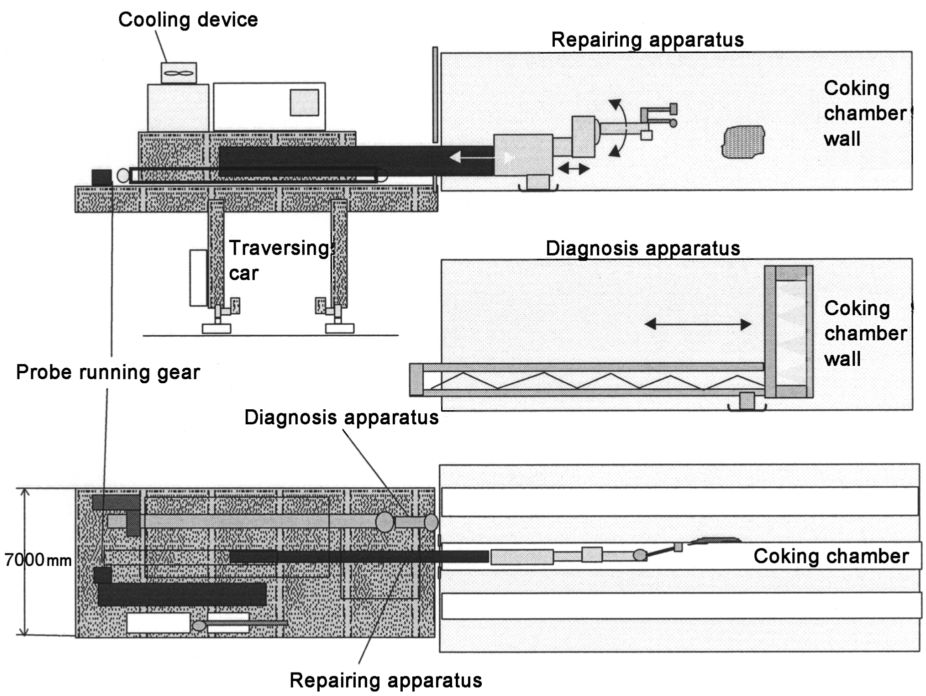

Fig. 4 Schematic diagram of the coking-chamber wall diagnosis and repair equipment

the diagnosis, it is possible to determine its position in the oven and its depth using the 3D coordinate data.

When repairing the coke oven chamber, the manipulator is inserted into the oven to repair the damaged part detected by the diagnosis by means of flame gunning. The manipulator is so designed that it is capable of continuous operation in the oven for a maximum of 3 hours. During that time, accurate positioning of the damaged part, setting of the scope of repair, preparation of a repair program and automatic flame-gunning repairs are carried out. The manipulator has a triple-axis articulated construction and is capable of freely moving in all directions – forwards and reverse along the length of the oven (X direction), vertical gyration in the direction of the oven height (Y direction) and horizontal gyration across the width of the oven (Z direction). It can be controlled with a high degree of precision (in minimum increments of 1 mm). The laser profile meter at the front end of the manipulator accurately measures the profile of the damaged part, making it possible to determine the irregularities of the oven wall surface with a contour map.

Using the above repair data, the scope of repair was set, programs for operating the descaling device and flame gunning burners were prepared, and the repair work on a fully automated basis was applied. Since the repair equipment is provided with cameras to monitor the oven interior during repairs, a heat-insulating plate to tightly cover the opening in the oven after insertion of the repair equipment is provided to prevent the damaged part from expanding as the oven body cools during the repair work.

5. Example of Diagnosis

5.1 Observation of oven walls

Fig. 5 shows a diagnostic image of the No. 2 coke oven at Nippon Steel's Oita Works. The diagnostic equipment is capable of photographing an entire oven wall at a time with exceptional definition. The image reveals vertical through-cracks in the oven wall at fairly regular intervals along the length of the oven. It also clearly shows the condition of carbon deposits on the wall. The deposit of carbon on the upper part of the coking chamber is especially conspicuous. In addition, defoliated brick surfaces and minute surface irregularities can clearly be observed.

5.2 Quantitative damage information analysis system

In order to speedily process data collected by the coke oven wall diagnostic equipment and reflect it in the repair plan, a quantitative damage information analysis system was developed. With this system, the operator judges the type of specific damage from photographic data that contains damage information, extracts quantitative damage information (position, area, irregularity) of the damaged part and inputs it into a database created for each coke oven. Examples of damage information output obtained from oven wall images are provided in **Figs. 6** and **7**.

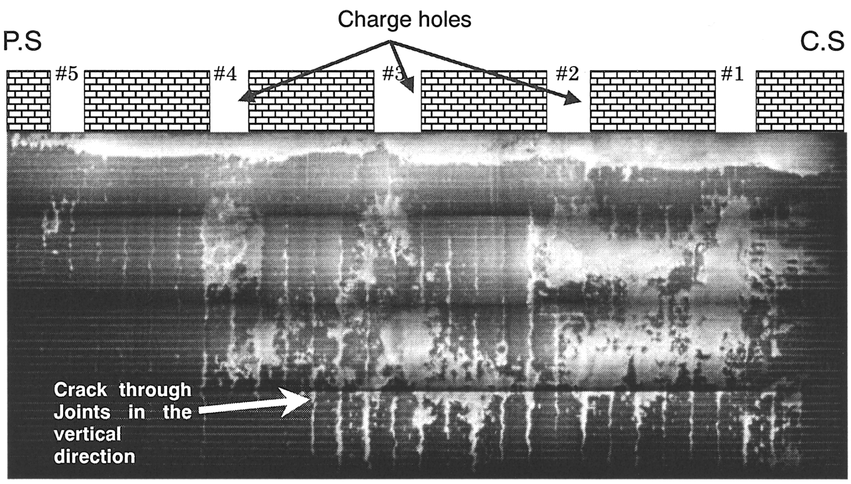

Fig. 5 Example of the wall surface of Oita No. 2 battery

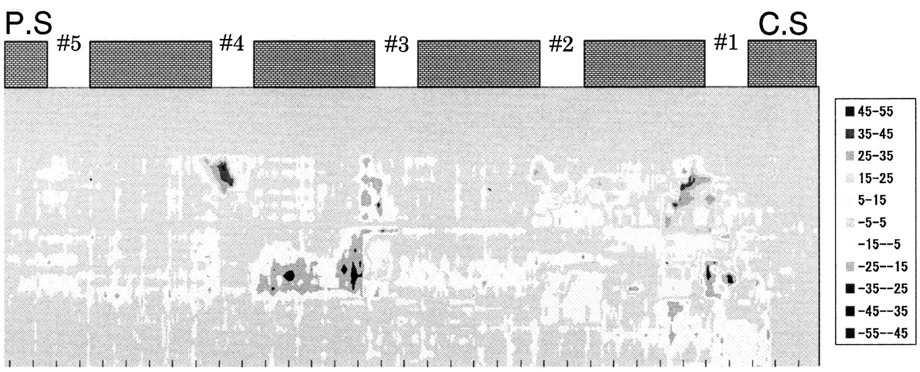

Fig. 6 Example of contour map of the wall

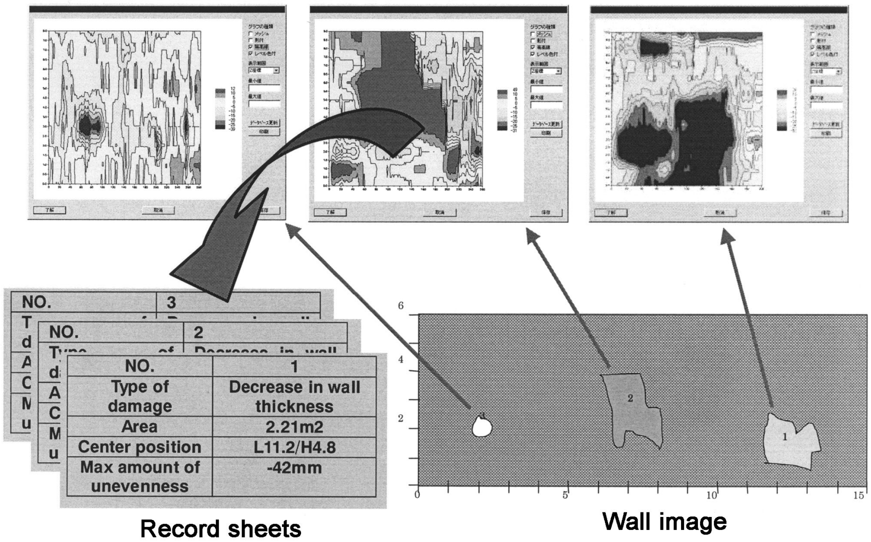

Fig. 7 Schematic diagram of the quantitative damage information analysis system

6. Example of Repairs

6.1 Automatic repair procedure

The automatic repair procedure with the newly developed repair equipment is shown below (see also **Fig. 8**).

(1) Insert the repair equipment into the oven.

(2) Accurately measure the profile of the damaged part and check for surface irregularities.

(3) Prepare a repair program (setting the scope of repairs, route of flame gunning, rate of flame gunning) in the operator's room above the equipment and transmit the repair program to the sequencer.

(4) Start the repair equipment (by pushing the start button), and the

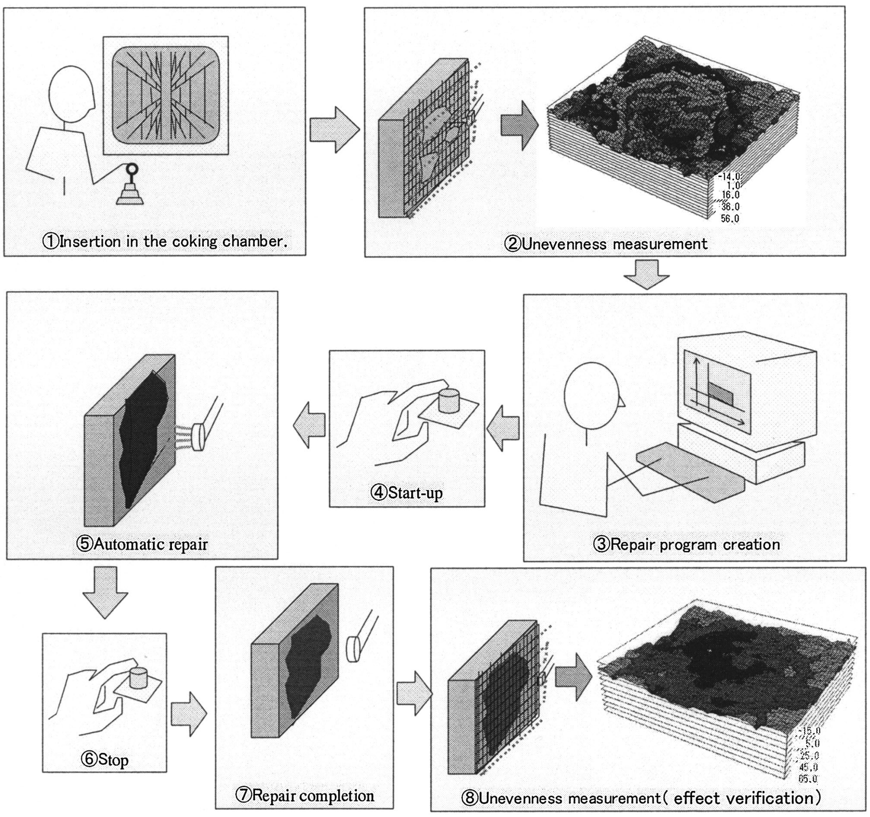

Fig. 8 Automatic repair process

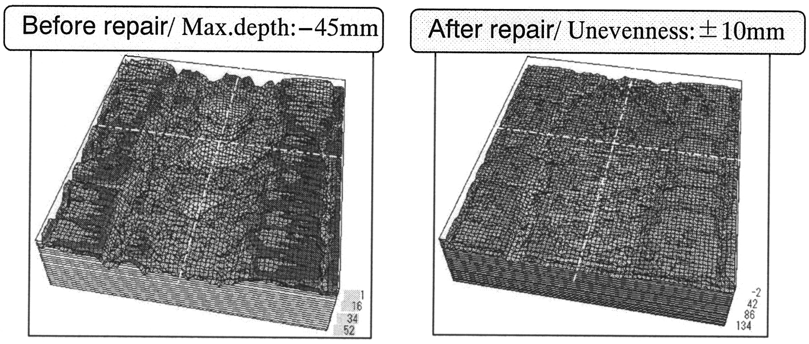

Fig. 9 Example of wall surface profile after repair

manipulator begins operating.

(5) Execute the repair work (under automatic control) and monitor the condition of the repair work by cameras installed in the oven.

(6) Stop the repair equipment (by pushing the stop button).

(7) Finish the repair work and stop the manipulator.

(8) Accurately measure the profile of the repaired wall and check the accuracy of the surface finish (condition of surface irregularities).

While the repair equipment is in the oven, the opening in the oven is tightly covered with the heat-insulating plate to limit any cooling of the oven body during the repair work.

6.2 Preparation of repair program

In the operator's room, the operator checks the measurement results and sets the scope of repairs on the personal computer for preparing repair programs. The operator also sets suitable parameters for the extent of flame gunning repair according to the depth of the damage. That completes preparation of the repair program.

6.3 Repair

Once the repair program has been transmitted to the sequencer of the repair equipment, the equipment is ready to start the repair work. The repair work can be started simply by pushing the start button on the equipment. After the equipment starts, the operator checks the progress of repairs on a TV monitor that displays images from the monitor cameras installed in the oven. The operator can stop the equipment any time simply by pushing the stop button.

6.4 Results of repair work

Fig. 9 shows part of the oven wall before and after repairs. Before the repairs, there were only dents in the wall up to a depth of about 45 mm. After the repairs, both the cross section and longitudinal section were within the target smoothness of ± 10 mm. The actual repairs took less time than initially planned, thus demonstrating the speed and accuracy of the repair work.

6.5 Efficiency of repair work

A comparison between the repair equipment and manual labor in terms of the repair work done in a given time showed that the new technology dramatically improved the efficiency and accuracy of repair work - by three times for repair depth, five times for repair area and three times for surface finish accuracy (**Fig. 10**). In addition, the new technology requires only two operators to carry out repairs which formerly required more than 10 repair workers. Furthermore, it completely eliminates the need for repair work at high temperature.

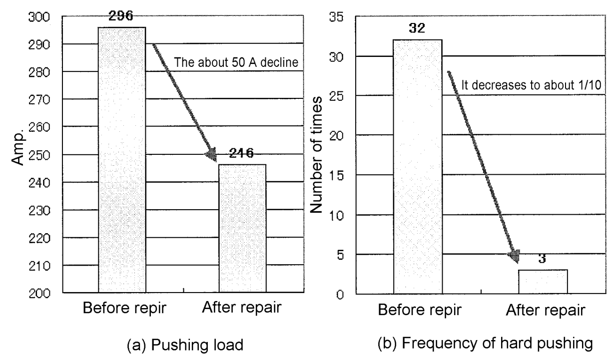

Fig. 10 Repair effect

6.6 Effects of repair

So far, the new system has been used to repair some 50 coking chambers in the No. 1 and 2 coke oven batteries (total 156 coke ovens) at Oita Works. It has produced a number of remarkable benefits. For example, the pusher current has been reduced by about 50 A on average and the incidence of hard pushing has decreased to about one-tenth. Concerning the durability of the oven walls repaired by the new technology too, even though some ovens have been in operation for three years since being repaired, all the walls remain in satisfactory condition and free from spalling.

7. Conclusion

The newly developed coking chamber wall diagnostic and repair system has made it possible to implement a speedy, quantitative diagnosis of coking chamber walls and speedy, highly accurate and efficient repairs of damaged walls based on the diagnostic results. In view of the aging of our coke ovens, the authors intend to positively promote periodic diagnosis of all the coke ovens in the batteries and special diagnosis of those ovens based on their operational information, carry out the diagnoses and repairs of coke ovens early and make the most effective use of the newly developed system so as to prolong the service life of the coke ovens.

This system is being transferred to each of Nippon Steel Corporation's steelworks with the aim of providing it as standard equipment for every coke oven. The system has already been installed at the Yawata and Nagoya Works, as well as the Oita Works. This equipment is working resolutely and effectively to secure oven lifespans of 50 years or more.