NIPPON STEEL TECHNICAL REPORT No. 94 July 2006

UDC 669 . 162 . 2

Latest Blast Furnace Relining Technology at Nippon Steel

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Abstract

Nippon Steel's blast furnaces in operation are nine at present, reduced by half in number, compared to those in the middle of the 1970s when large blast furnaces of the 5,000 m^3-class inner volume began to be constructed. During that time, given the increasingly urgent imperatives for total-cost reduction, such as each furnace's upward flexibility in production, longer service life, labor savings, shorter relining periods, etc., we have vigorously pressed forward with the development and industrialization of corresponding equipment technologies. Some of the new equipment technologies achieved against this background include: the inner-volume expansion during relining, the hearth-wall life extension by the improved quality of carbon blocks, the shaft life extension by the adoption of copper staves, mechanization of cast house works, and shortening a relining period by the large block method. The application of these technologies has resulted in substantial functional improvement and life extension of blast furnaces, while at the same time making it possible to minimize production decrease needed during relining. This paper describes salient features of these latest blast furnace relining technologies.

1. Introduction

As represented by the construction of large-scale blast furnaces (inner volume: 4,000 m^3 or more) in the early 1970s, Japanese blast furnace equipment technology made dramatic progress in response to the ever-increasing demand for steel during the period of rapid economic growth. Thereafter, Japan experienced the oil crises, yen appreciation, bubble economy, and more recently, special procurement orders from China. All this has drastically changed the country's demand and industrial structures. Under that condition, the most important requirements of blast furnaces are to cut total costs and enhance the production elasticity through improvement of equipment controllability, saving of energy and labor, conservation of natural resources, extending blast furnace life, and so on. Well aware of those requirements, Nippon Steel Corporation has continually developed its blast furnace equipment technology and applied its latest equipment technology in the relining of blast furnaces.

This paper describes the company's latest blast furnace relining technology, specifically expansion of blast furnace inner volume, extending blast furnace life, mechanization of cast house work and shortening of the relining period.

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2. Expansion of Blast Furnace Inner Volume

At present, Nippon Steel has nine blast furnaces in operation (includes the No. 2 BF at Hokkai Steel Muroran Works). This is just half the number of blast furnaces the company was operating in the mid-1970s. Under this condition, the company has expanded the inner volume of each of its blast furnaces during relining and enhanced the production elasticity and functions of the individual blast furnaces significantly so that it can promptly respond to even a sudden and substantial increase in demand. In expanding the inner volume of each individual blast furnace, the company avoids making major modifications to the equipment from the standpoint of keeping the cost of relining within reasonable limits. As a rule, the blast furnace inner volume is expanded by increasing the furnace diameter with the furnace height kept almost unchanged. Judging from operational results obtained in the past, the company considers that given a certain inner volume, a blast furnace which is small in height and large in diameter is better than one large in height and small in diameter in terms of permeability and tapping efficiency.

Fig. 1 shows the results of the recent inner volume expansion of the company's blast furnaces now in operation. In the case of economical inner volume expansion without substantial alteration to the blast furnace foundations, top structure, etc., the ratio of inner volume expansion is 10 to 25%, including the effect of reduction of shaft wall thickness. The average inner volume of the company's blast furnaces, including Kimitsu #4 BF (5,555 m^3 after its 3rd relining) and Oita #2 BF (5,775 m^3 – world's largest – after its 3rd relining), has been expanded to 4,490 m^3 [1].

3. Technology for Prolonging Blast Furnace Life

Nippon Steel has taken, during relining of any of its blast furnaces, suitable measures to prolong the life of the hearth and shaft that govern the service life of the blast furnace. As a result, and thanks to improvements in furnace operating techniques, the company has been able to extend the service life of all its blast furnaces without causing productivity to decline.

Fig. 2 shows records of the campaigns and productivity of each individual blast furnace at Nippon Steel. The campaigns of those blast furnaces that were blown out in the 1970s were 5 to 7 years. After that, the campaign of blast furnaces was extended to 10 to 12

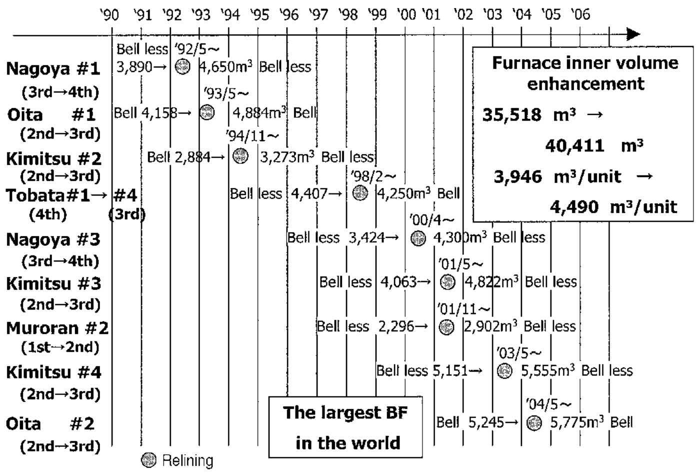


Fig. 1 Expansion of blast furnace inner volume at NSC

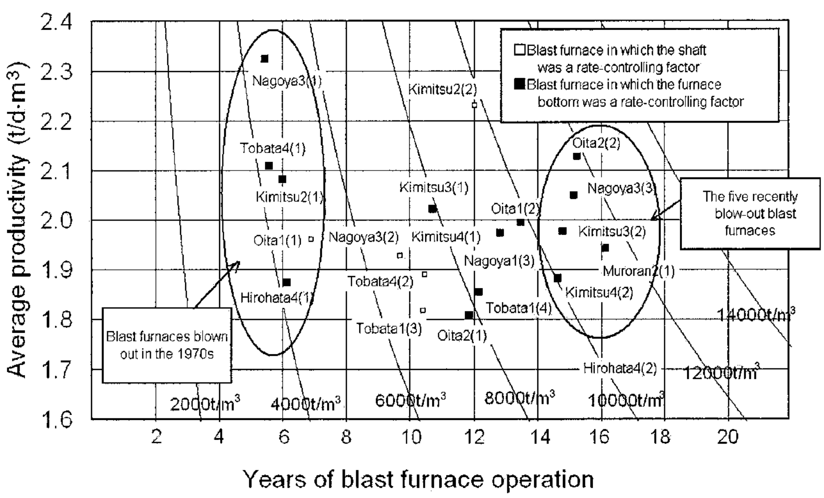


Fig. 2 Actual campaign life of NSC's blast furnaces

years. The blast furnaces that were blown out most recently had a campaign of about 15 years while maintaining high productivity. The cumulative iron yield of the blast furnaces that were blown out recently is 10,000 to 12,000 tons.

With the blast furnaces blown out recently, the hearth is the major factor that governs the furnace campaign, although the shaft was also a major governing factor for some time in the past. In the meantime, Nippon Steel has taken suitable measures, mainly with the hearth and shaft, to prolong the blast furnace life[1-4].

3.1 Measures to prolong hearth life

As measures to prolong the hearth life, the company has increased the hearth cooling capacity and improved the qualities of carbon blocks used for the hearth. For the hearth sidewall section that is subject to the most erosion (the part below each taphole), a cast iron stave or copper stave offering high heat conductivity has been used. In addition, the temperature of the cooling water has been lowered.

For the hearth, a two-step cooling system, doughnut-shaped cooling system, etc. whose cooling rate is adjustable is employed to prevent the deadman from becoming inactive due to overcooling. For the bottom refractory, a combination of carbon blocks and inner ceramic lining is used.

The service life of carbon blocks has been prolonged mainly through improvements in the thermal conductivity and molten iron resistance of the refractory materials. The refractory life of carbon block BC-5 that was developed in 1965 was 5 to 10 years at most. To prolong the refractory life, various new carbon blocks have been developed. For example, CBD-2 that features micro-pores has a service life of 15 years while CBD-2RG, a newer carbon block, can withstand more than 15 years of use.

For those blast furnaces that were relined after the third relining of the No. 2 blast furnace at Kimitsu Works in 1994, carbon block CBD-3RG – an improved version of CBD-2RG – has been adopted. The salient characteristic of this new carbon block is that man-made graphite is used in place of anthracite to make the refractory material more homogeneous and thereby improve the thermal conductivity without sacrificing the advantage of micro-pores and the good molten iron resistance of CBD-2RG. More recently, CBD-GT1 (carbon block with TiC added)[5] that affords far superior corrosion resistance than CBD-3RG was adopted for the No. 4 blast furnace at Kimitsu Works (3rd relining) and the No. 2 blast furnace at Oita Works (3rd relining).

Nippon Steel has collected core samples of the hearth sidewall carbon blocks right after the blowout and cooling of blast furnaces and subjected them to in-depth analyses. **Fig. 3** shows examples of these core samples. The core sample of BC-5 from the No. 4 blast furnace at Hirohata Works (2nd relining) exhibited a brittle layer about 300 mm in thickness on the hot face. The core sample of CBD-2 with improvement of micro-pores used for the No. 2 blast furnace at Muroran Works (1st relining) had a disintegrated portion about 100 mm in width, but the brittle layer thickness was small. At present, several blast furnaces that are lined with still better carbon blocks are in operation. It is expected that the life of their hearths will increase significantly thanks to the favorable effects of micro-pores, etc.

Taking into account the intensified cooling and improved carbon block material, estimations were made for the rate of carbon block wear. The results are shown in **Fig. 4**. Assuming that the blast furnace can continue operation till the hearth sidewall thickness decreases to 400 mm, it can be expected from Fig. 4 that the hearth will stand use for some 25 years[2-4].

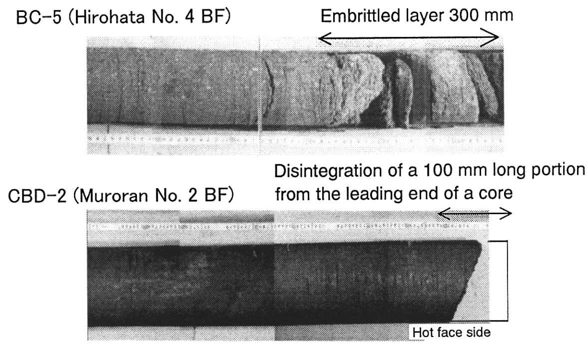


Fig. 3 Core samples of carbon blocks

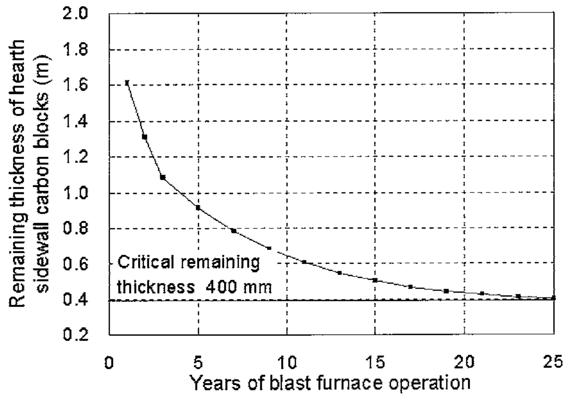


Fig. 4 Estimated furnace bottom life after measures to prolong campasgn life

3.2 Measures to prolong shaft life

Since Nippon Steel introduced cast iron staves from the former Soviet Union in 1969, it has made various improvements to improve their durability. **Fig. 5** shows the history of improvements the company has made to enhance the cooling functions of cast iron staves. For some time after their introduction, broken stave pipes were a frequent occurrence and the blast furnace campaign was not more than about five years. From the results of stave core sample examinations and dissection examinations, it was assumed that the damage to staves was due to deterioration of the cast iron base caused by thermal load fluctuation in the furnace. Therefore, the stave material was changed from FCH to FCD. At the same time, the cooling system was switched from natural cooling to forced circulation of pure cold water. In addition, various measures to enhance the cooling efficiency were implemented, such as narrowing of the pipe spacing and the installation corner cooling pipes and rear serpentine pipes.

The fourth-generation staves are of a thin-walled unit construction made up of a brick cast in the stave. This unit construction has eliminated the need for bricklaying work and minimized the change in hot face profile, contributing in stabilization of the blast furnace operation. Recently, with the aim of further stabilizing the blast furnace operation through maintenance of stable hot face profile, reduction of stave wall thickness and elongation of stave life, the company introduced a copper stave to the No. 4 blast furnace at Kimitsu Works (3rd relining) (**Photo 1**)[6] and the No. 2 blast furnace at Oita Works (3rd relining) that were relined most recently.

Before adopting a copper stave for the shaft, the copper stave

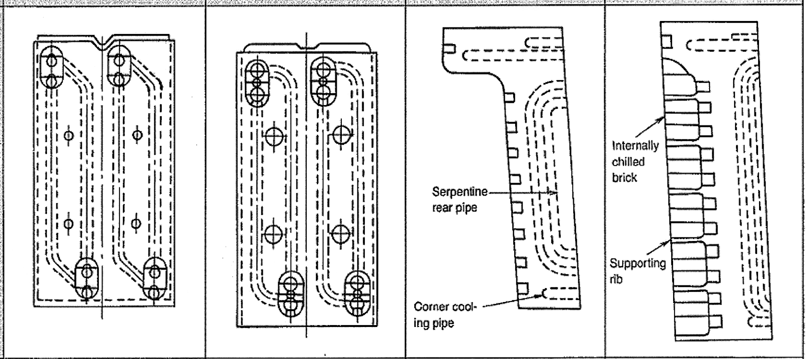
	First generation	Second generation	Third generation	Fourth generation
Construction				
Main improvements		1. Perpendicularly bent corner pipe 2. Cooling with cold pure water	1. Installation of corner cooling pipe 2. Installation of serpentine rear pipe	1. Use of monolithic stave-brick assembly 2. Reduction in wall thickness
Year of introduction	1969~	1974~	1977~	1985~

Fig. 5 Changes in NSC's staves

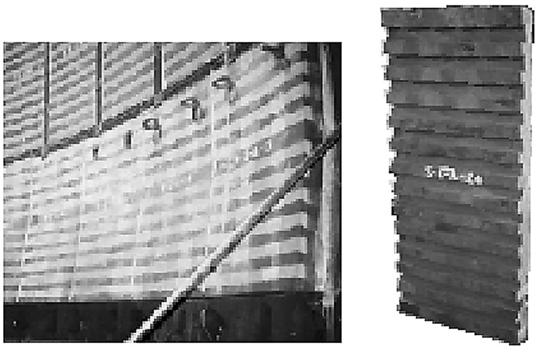


Photo 1 Shaft copper staves

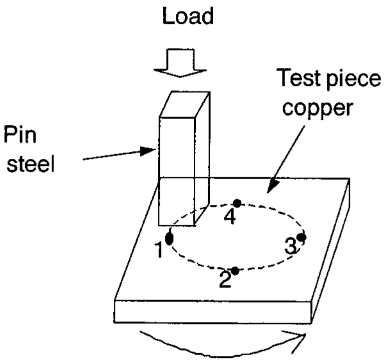


Fig. 7 Method of off-line wear test

was subjected to an off-line wear test on the basis of the results of an analysis of its thermal conductivity to confirm whether there were any problems in terms of the wear resistance of copper staves. In the three-dimensional steady-state thermal conductivity analysis shown in **Fig. 6**, assuming that the in-furnace gas temperature is 1,200℃, the maximum temperature at the front end of the rib was approximately 200℃, much lower than that of the cast iron stave (760℃). From this result, it is estimated that the maximum temperature does not adversely affect the strength of the copper stave base material.

Fig. 7 shows the off-line wear test procedure. The atmospheric temperature was set to 220℃, the pushing load was calculated by Janssen's equation, and the test piece rotational speed was determined from the burden descent velocity. According to the off-line test, the average amount of wear of the copper stave is estimated to be 0.17 mm per year, or a total amount of wear of approximately 5 mm in 25 years. Therefore, it was thought that the copper stave will not suffer any problems in terms of wear resistance.

Fig. 8 shows the result of estimation of the shaft life. With the

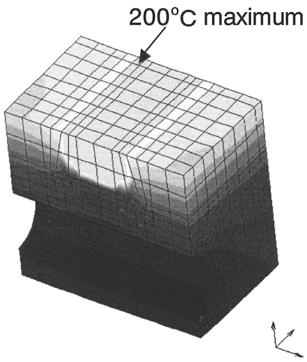


Fig. 6 Estimated temperature distribution of shaft copper staves

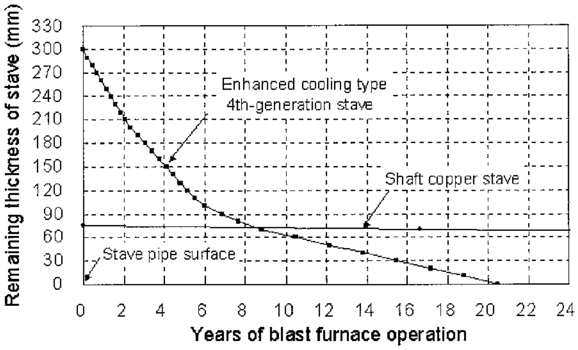


Fig. 8 Estimated shaft life

fourth-generation enhanced cooling type of cast iron stave, it is estimated that damage will reach the stave pipe surface some 20 years after blow-in. Thus, the life of these cast iron staves is 20 years or so. On the other hand, it is expected that the copper stave will stand use for 25 years or more since it wears very slowly thanks to the lower hot face temperature and the maintenance of its mechanical strength[2-4].

4. Mechanization of Cast House Work

With the aim of saving labor and reducing stress in the cast house work, the company has made earnest efforts to achieve mechanization, remote-controlled operation and even fully automatic operation. **Table 1** shows examples of cast house equipment[3,4]. In order to permit handling even high-grade mud, the company developed a hydraulic taphole opener for the first time in the world some 15 years ago. In addition, the mud gun has been made much more powerful to improve the accuracy of molten iron/slag discharging work dramatically. Furthermore, the monitor screen layouts have been made sophisticated enough to allow not only for radio-controlled operation, but also remote-controlled operation from the instrument room. The accuracy of level measurement/weighing has also been improved and automatic switching of the tilting runners for molten iron has been implemented. **Fig. 9** shows the labor-saving devices.

5. Shortening Relining Period

Since blast furnaces operate continuously at high temperatures, they need to be relined periodically. On the other hand, at integrated iron and steel works, not only finished and half-finished products but also energy and logistical balance are designed on the precondition that each individual line maintains a prescribed level of operation. Thus, they have limited leeway. In this context, even though blast furnaces are relined on a planned basis, shutting down a blast furnace – the main line in the most upstream process – for an extended period of time causes great inconvenience.

Therefore, Nippon Steel has made a companywide effort to develop new equipment technology and put it into practical use. As a result, the company has succeeded in significantly shortening the relining period for the No. 3 blast furnace at Nagoya Works (4th relining), which was put back into operation in April 2000, and the blast furnaces that were relined subsequently. **Fig. 10** compares the conventional relining method and the large block method employed by Nippon Steel. With the conventional method, much labor is involved in cutting the shell into strips and welding them together at the work site since the shell strips have to be carried out of and into the blast furnace paddle. By contrast, with the large block method,

Table 1 Cast house equipment

	Mechanization	Remote controlled operation	Automation
High power mud gun	○	○	
Hydraulic tap hole opener	○	○	
Cover traverser	○	○	
Mud filling device	○		
Rod changer	○		
Oxygen tap hole opener	○		
Iron slag separation tub	○	○	
Hot metal level gauge and weigher	○	○	○

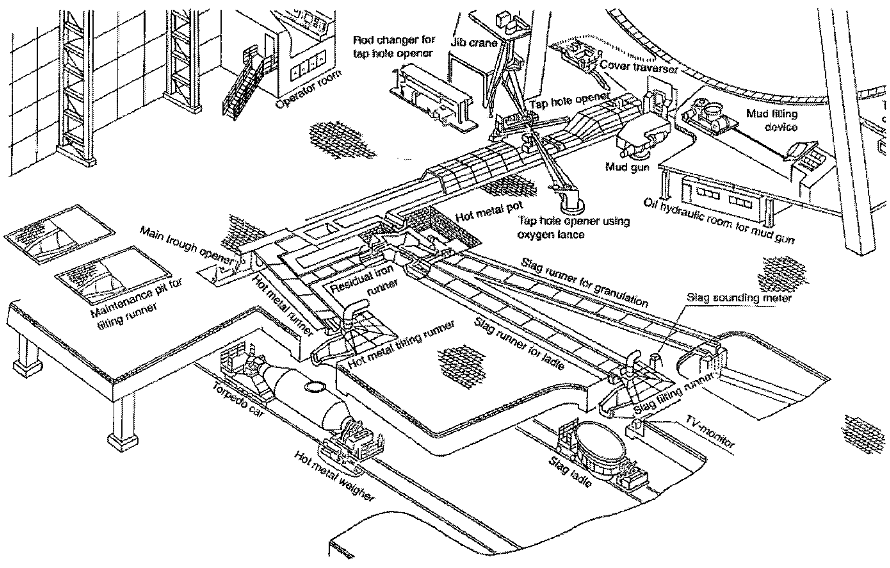


Fig. 9 Simplified perspective diagram of cast house equipped with labor saving machines

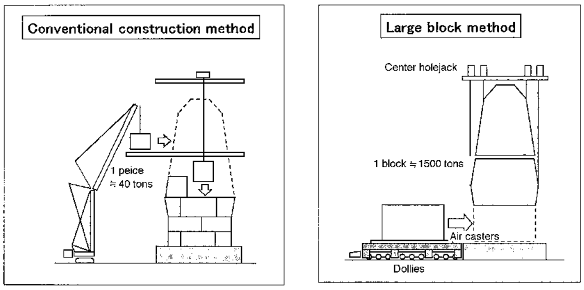


Fig. 10 Comparison between conventional and large block method

which employs a center hole jack, air castors, dolly conveyor, etc., the shell is horizontally cut into four pieces or so and each of those pieces is removed together with the associated stave in the form of a ring. When installing the cut pieces, they are assembled into rings and taken into the top structure. Since the large block method is based on off-line work, it offers significant advantage in terms of the quality of welds and the safety of the work.

Nippon Steel applied the large block method for the first time in the relining of the No. 3 blast furnace of its Nagoya Works (4th relining). In the third relining of the No. 4 blast furnace at Nippon Steel Kimitsu Works, the hearth brick modular construction method using larger blocks was applied. For the third relining of the No. 2 blast furnace at Nippon Steel Oita Works, the scope of application of the modular construction method was further expanded (**Photo 2**) and a new method for supporting the heavy blocks was developed. As a result, the relining work involving expansion of the furnace inner volume could be carried out in a comparatively short period of time[6-8].

Fig. 11 compares the planned relining period using the conventional method and the actual relining period using the large block method for the No. 3 blast furnace at Nagoya Works (4th relining) with the actual relining period for the No. 4 blast furnace at Kimitsu Works (3rd relining) and No. 2 blast furnace at Oita Works (3rd relining), respectively. By applying the large block method to its No. 3 blast furnace, Nagoya Works could shorten the relining period by 35 days, or 27%. Kimitsu Works, which employed the newer technology, completed the relining of its No. 4 blast furnace in 88 days, and the Oita Works, which also adopted the newer technology, finished the relining of its No. 2 blast furnace in 79 days[1].

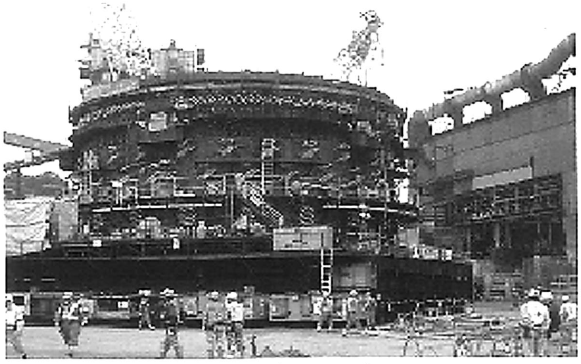


Photo 2 Module construction

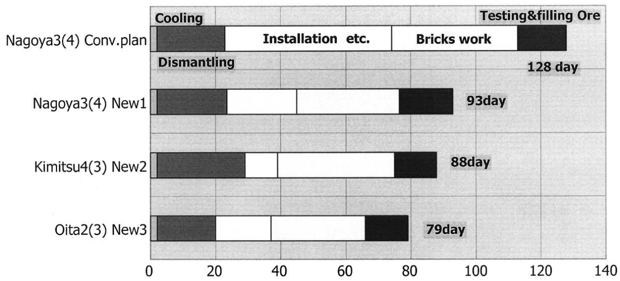


Fig. 11 Comparison of relining terms Nagoya No. 3, Kimitsu No. 4 and Oita No. 2

6. Conclusion

The discussion above focuses on Nippon Steel's latest blast furnace relining technologies, specifically the expansion of the furnace inner volume, extending furnace life, mechanization of the cast house work and shortening of the relining period. These technologies have contributed to the improvement in productivity and operational stability of large-scale blast furnaces and to the elongation of blast furnace life. In particular, it can be expected that the campaigns for blast furnaces will increase to 25 years or more in the future. The authors intend to continue pressing ahead with the development of new equipment technology that supports further sophistication of blast furnace operating techniques and to further raise the level of our blast furnace equipment technology.

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