

Two Decades of Improvements in Refractory at Nippon Steel Corporation

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Abstract

Outline of the improvement of refractories technology for these twenty years in Nippon Steel Corporation is described briefly. Refractories technology : Refractories material, brick-work, repair, diagnosis, demolish and recycle has took advantage, as result the refractory consumption has been decreased steadily in severe condition with the strict quality demand for steel products and the dramatically changing amount of steel production. The technology progress in NSC has been tried advance and kept the position in overseas market improvement.

1. Introduction

This paper describes the advances in refractory technology that Nippon Steel has made over the past 20 years. Amid the increasingly stringent demand for steel refining processes reflecting the continual increase in the proportion of high-grade steel and the dramatic growth of crude steel output, in the field of Refractory Ceramics R&D, our company has steadily reduced its specific refractory consumption and continually enhanced the international competitiveness of its refractory technology. It has achieved this by making the most effective use of its R&D into refractory materials for the individual manufacturing processes and on new technologies for furnace construction, repair, diagnosis, demolishing and recycling.

2. Changes in Steel Manufacturing Situation Pertaining to Refractory Technology

2.1 Adaptation to upward/downward flexibility of steel output

Fig. 1 shows the changes in crude steel production (1988-2006) throughout the world, in Japan and at Nippon Steel.^{1,2)} Despite the steady rise in the cost of raw materials, global crude steel output has increased to more than 1,200 million tons per year thanks to increased demand from the BRICs. On the other hand, Japan's crude steel production, which bottomed out in 1992-95, has since been on the rise again, with annual output exceeding 100 million tons for the past few years. At Nippon Steel, crude steel output has exceeded 33 million tons per year for the first time. The annual output of the Nippon

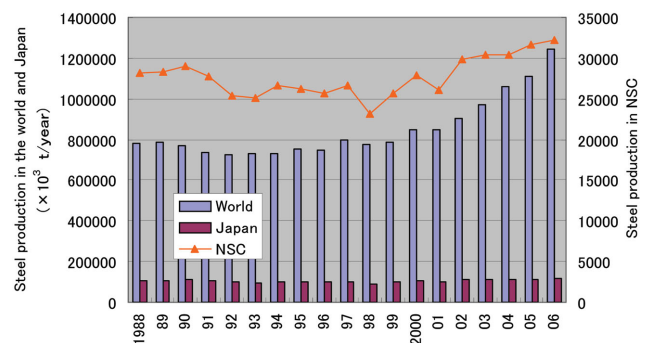


Fig. 1 Transition of steel production

Steel Group as a whole has expanded to more than 40 million tons. During this time, the company has made various improvements to its increasingly polarized production system—to attain higher productivity and in response to upward production flexibility during low levels of production. In order to cope with production fluctuations, the Refractory Ceramics R&D Div. of the company has made strenuous efforts to improve its refractory technology and enhance the productivity and efficiency of its refractory maintenance work.

2.2 Increasing demand for higher-quality, higher-function steels

Concerning sheet steel products typified by automotive sheeting, the development of higher-strength steels has steadily progressed due to the ever-increasing demand for safer and lighter car bodies,

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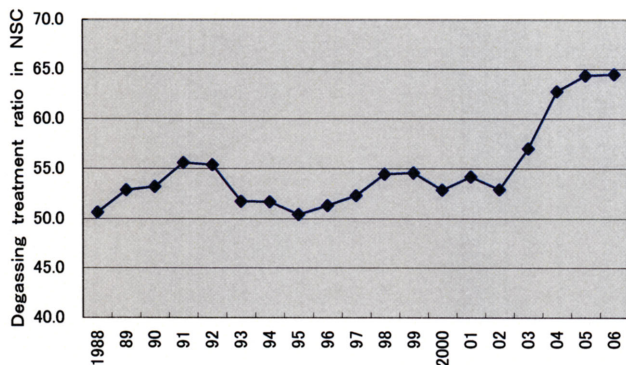


Fig. 2 Transition of degassing treatment ratio

quiet, high-efficiency motors, and lead-free plating, etc. to bolster efforts to conserve the environment and save energy.³⁾ With respect to heavy plate steel products, there is growing demand for weather-proof steel for unpainted bridges, corrosion-resistant steel for huge container vessels in the 6,000-TEU class which are increasingly employed to cope with the ever-expanding global physical distribution, and pitting corrosion-resistant steel for oil tankers of double-hull construction that has been made mandatory to prevent environmental pollution in the event of a collision between two tankers at sea (this type of steel appreciably slows the development of pitting corrosion).⁴⁾

As for natural gas pipelines—a promising source of clean energy from the standpoint of the current environmental and energy situations, there is strong demand for steel having not only high strength and low-temperature toughness, but also good on-site weldability and sour resistance (i.e. resistance to hydrogen-induced cracking and sulfide-induced stress corrosion cracking).⁵⁾ As for shaped and wire rods, typical use of which is steel cord, extra-high cleanliness has been called for, since rupturing of the steel due to nonmetallic inclusions in the drawing process must not occur.⁶⁾ Thus, amid the increasingly stringent quality requirements for steel products, steel refining processes have changed markedly. As an example of a major operational index for refining processes, the degassing treatment ratio at Nippon Steel is shown in Fig. 2. Over the past two decades, the ratio has increased by some 15%. In recent times, in particular, the quality requirements for steel have become extremely stringent. This situation has presented a major challenge to the company's refractory technology too.

3. Changes in Domestic Refractory Production and in Specific Refractory Consumption/Furnace Maintenance Costs at Nippon Steel

3.1 Refractory output

In contrast with crude steel output, domestic refractory output has been decreasing year by year as shown in Fig. 3.⁷⁾ Concerning general-purpose fired clay, high alumina bricks, and unburned magnesia-graphite bricks, etc., these have continually been replaced by bricks imported from China and some other countries as shown in Fig. 4.⁸⁾

In Japan, the emphasis in refractory production has shifted to functional refractories, mainly concerning the nozzles used in continuous casting that largely determine the quality of steel, and to monolithic refractories which can be manufactured with high productivity. Most recently, however, the appeal of inexpensive refractories made in China is diminishing following abolition of the return

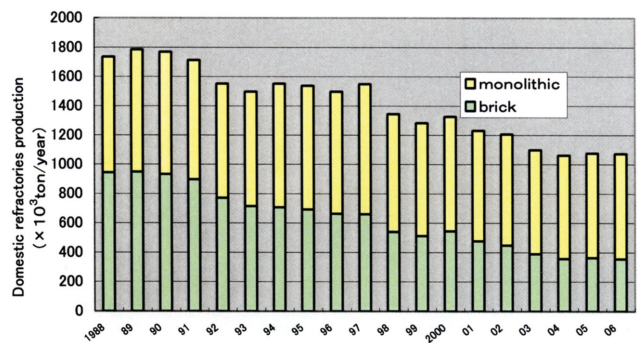


Fig. 3 Transition of domestic refractory production

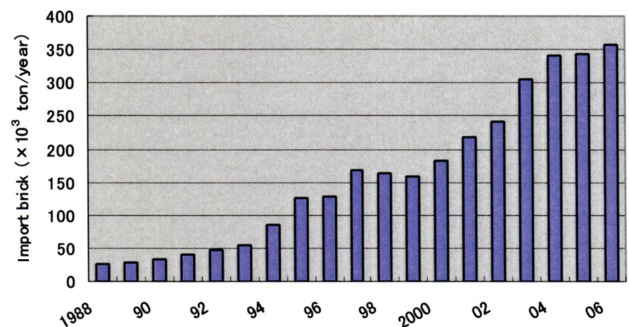


Fig. 4 Transition of amount of import refractory

rate for value-added tax and in the increased export duty rates. Therefore, some Japanese refractory users are returning to domestic products.

3.2 Changes in specific refractory consumption and proportion of monolithic refractories at Nippon Steel

The iron and steel industry is said to consume a large volume of refractory. At Nippon Steel, we have reduced total specific refractory consumption from the ironmaking process to the rolling process by about 2 kg/t-s, down from about 9.5 kg/t-s to 7.5 kg/t-s over the past 20 years (Fig. 5). The switch from brick to monolithic refractory contributed much to this achievement. Fig. 6 shows the change in the proportion of monolithic refractory during that period. Thanks to the improvements in furnace construction technology and refractory material technology that were made to mechanize furnace construction work, save labor and offset the shortage of bricklayers, the

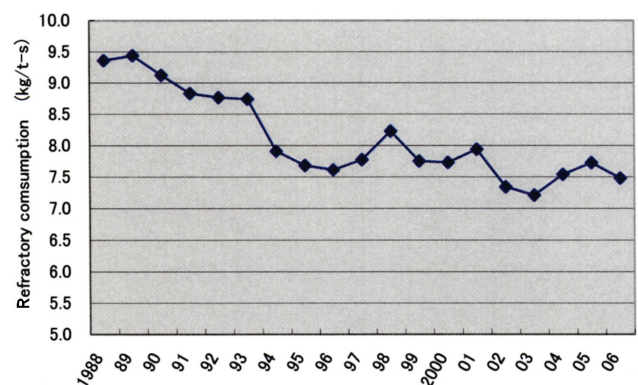


Fig. 5 Transition of refractory consumption in NSC

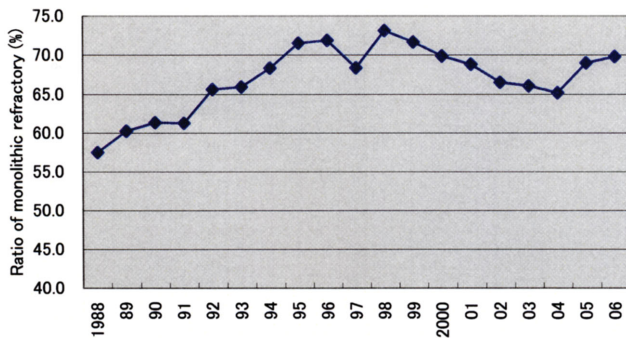


Fig. 6 Transition of application ratio of monolithic refractory in NSC

proportion of monolithic refractory has rapidly increased since the 1980s. At present, it is around 70%.

3.3 Changes in furnace maintenance work costs at Nippon Steel

On the other hand, the cost of furnace maintenance work has been cut appreciably as shown in Fig. 7 through the development and use of equipment to mechanize the maintenance work and save labor,⁹⁾ as well as through better management of the pool of construction workers that was enabled by the integration of repair shops which were formerly decentralized. However, since the number of qualified and skilled workers required to build furnaces has declined while the number required to maintain the repair and maintenance equipment has increased, it has become necessary to diversify the types of construction work and render their contents more sophisticated.

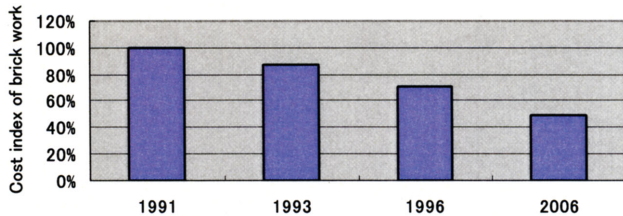


Fig. 7 Transition of cost index of brick work in NSC

4. Reorganization of Refractory Ceramics R&D Div. at Nippon Steel and Change in Numbers of Refractory Researchers, Engineers and Furnace Maintenance Workers

4.1 Change in number of refractory researchers and engineers

Formerly, the company's organization of refractory engineering consisted of steelworks departments, which were mainly responsible for the maintenance and improvement of manufacturing equipment at the steelworks and for the development and application of new technologies, and two R&D centers engaged in basic studies, technological developments and engineering for major projects (see Table 1).

With the decline in crude steel production, the organization—which initially had a large staff of more than 100 members—was reorganized. Namely, the steelworks (refractory) department was transferred from the equipment division to the steelmaking department, which consumes a large volume of refractory. On the other hand, the R&D centers were once divided into two groups; one engaged in the application of fine ceramics and the other in the development of furnace refractory materials. In 1991, they were incorporated into the Central R&D Center as the present-day Refractory Ceramics R&D Div. Each time the organization was changed, the number of R&D staff was rationalized as required by contemporary needs. In terms of the absolute number of refractory researchers and engineers, the figure has shrunk to about half in the past two decades (see Fig. 8).

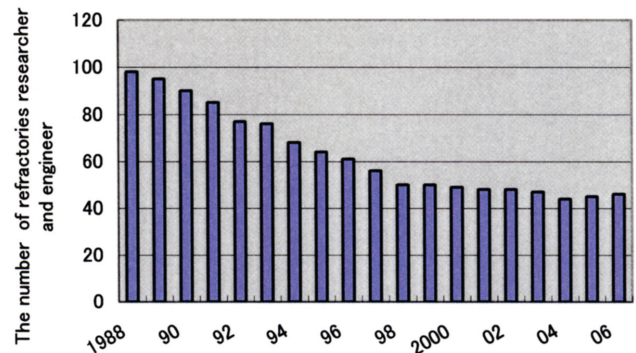


Fig. 8 Transition of the number of refractories researcher and engineer in NSC

Table 1 Transition of organization of refractories division in NSC

Period	Outline of organization of refractories division in NSC
June in 1972	Refractories Sect., Yawata and Hirohata Refractories Development Dept., Heat Technology Div., Plant Engineering & Technology Bureau
November in 1976	Refractories Dept., Yawata and Hirohata Refractories Development Dept., Heat Technology Div., Plant Engineering & Technology Bureau
July in 1988	Refractories Development Dept. and Fine Ceramics Development Process Development Div., Plant Engineering & Technology Bureau
November in 1991	Reorganization to Refractories & Ceramics Process Technology Research Laboratories, Technical Development Bureau
July in 1994	Mechanical Technology & Refractory Development Center, Process Technology Research Laboratories
July in 1997	Refractories Engineering Group transfer to Engineering Dept., Mechanical Div., Plant Engineering & Technology Center
July in 1999	Reorganization to Refractory Ceramics R&D Div., Steel Research Laboratories, Technical Development Bureau
April in 2002	Refractory Ceramics R&D Div., Environment & Process Technology Center

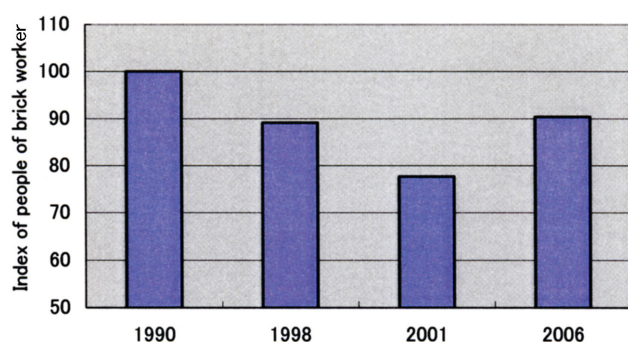


Fig. 9 Transition of the number of brick worker in NSC

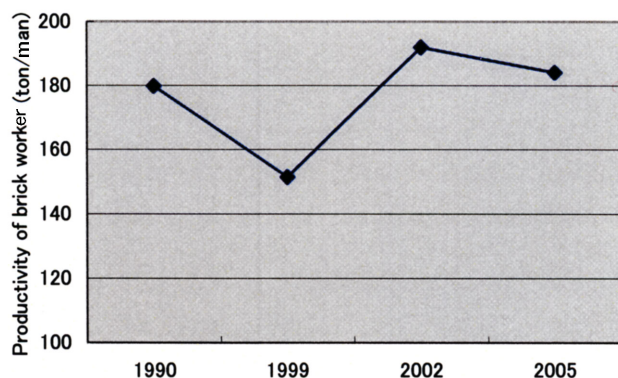


Fig. 10 Transition of productivity index of brick worker in NSC

4.2 Change in number of furnace maintenance workers and their present conditions

Fig. 9 shows the change in number of refractory maintenance workers at the steelworks of Nippon Steel. By around 1995, the number was reduced to about 1,100 as a result of rationalization efforts. Today, however, with the increase in the amount of furnace equipment as a result of expanding steel production, the absolute number of workers is on the rise. Fig. 10 shows the change in labor productivity expressed in terms of the number of tons of refractory handled per worker. It can be seen that productivity has improved noticeably thanks to efforts to mechanize the brick-laying work and cut down on worksite labor. Today, however, in view of the aging of many of the bricklayers, it is urgently necessary to ensure a smooth transmission of know-how and techniques from experienced bricklayers to their young and middle-aged colleagues and to foster skilled bricklayers.

5. History of Installation/Shutdown of Ironmaking and Steelmaking Processes at Nippon Steel

5.1 Ironmaking process

Since the shutdown of the Tobata No. 4 blast furnace in 1988, Nippon Steel has shut down three blast furnaces at its Kamaishi, Sakai and Hirohata Works, reducing the total number of blast furnaces from 13 to 9. After that, as shown in Fig. 11, the company has continually expanded the capacity of each of the blast furnaces during relining. Today, large blast furnaces exceeding 5,000 m³ in inner volume are the mainstream, and increasing importance is attached to refractory technology, such as the hearth carbon block,^{10, 11)} which allows for high productivity of the large blast furnaces. On the other hand, as shown in Fig. 12, the average age of the company's coke

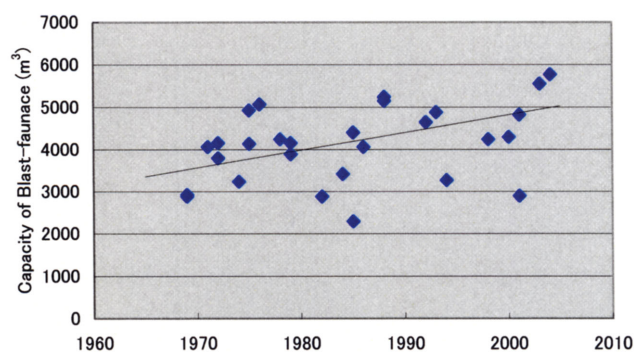


Fig. 11 Transition of capacity of blast-furnace in NSC

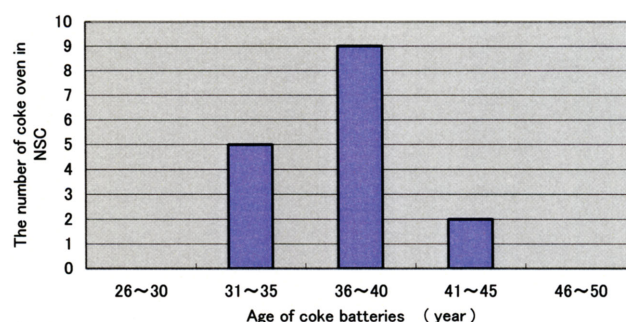


Fig. 12 Age of coke-batteries in NSC

ovens has exceeded 37.¹²⁾ As a result, difficulties in pushing in coke and holes in the coking chamber bricks occur not infrequently, causing productivity to decline. Various measures to prolong coke oven life are now being implemented and plans to install new coke ovens and renovate the existing ones are being discussed. Under those conditions, it is important to develop new repair and diagnostic techniques in the future. Concerning the mass procurement from abroad of silica brick, which is no longer manufactured in Japan, ensuring stable quality and steady supply will be major problems.

5.2 Steelmaking process

Around 1979, the removal of silicon from hot metal in the casting house, the pretreatment of hot metal (ORP) in the mixing car,¹³⁾ and the practice of top- and bottom-blowing of oxygen in the converter (LD-OB)¹⁴⁾ were started at the company's steelworks. It is no exaggeration to say that those improvements have almost completed the steel refining processes of today and that unburned bricks made from composite raw materials, such as magnesia-graphite brick and alumina-silicon carbide-graphite brick,^{15, 16)} represent some of the refractory material technology that has been developed in concert with the above refining processes.

Concerning the secondary refining of steel, various types of processes have been developed to meet the increasingly sophisticated and diverse quality requirements of steel (see Fig. 13).¹⁷⁾ In those processes, electro-cast magnesia-chromium bricks, rebonded bricks,¹⁸⁾ semi-rebonded bricks, and direct-bonded bricks,¹⁹⁾ have been applied. With respect to continuous casting equipment too, new types of machines, such as the twin-belt caster and the strip caster (see Fig. 14),²⁰⁾ have actively been developed. Today, refractory brick for continuous casting of steel not only performs the functions of distributing molten steel, shutting out air and preventing molten steel from scattering about during continuous casting, but it also functions as one

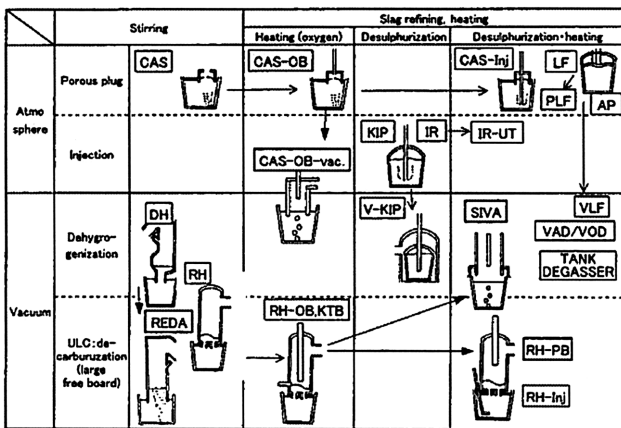


Fig. 13 Classification of second refining process in steel making

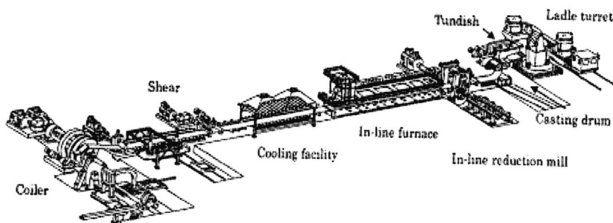


Fig. 14 Outline of strip castor by twin-drum

of the most important parts of the continuous casting machine to permit casting high-quality steel on a stable basis. With the development of the new refining processes and continuous casters mentioned above, the company's refractory technology has improved remarkably.

5.3 Rolling process

As for the reheating furnace in the rolling process, the continuous galvanizing line has been expanded to meet the increasing demand for automotive sheet. From the standpoint of saving energy for the reheating furnace, the use of a regeneration burner and ceramic fiber has been rapidly promoted at the steelworks.²¹⁾ On the other hand, the damage to ceramic fibers caused by oxidized scale scattering about in the furnace, the absence of operation monitoring technology to diagnose the soundness of refractory, and the impact of ceramic fiber on the environment and human health, etc. in connection with the harmfulness of asbestos have become problems.²²⁾

5.4 Other

As shown in Fig. 15, individual steelmakers have initiated the development of various new ironmaking processes.²³⁾ Nippon Steel developed and put into use the slag minimum process (SMP)²⁴⁾ at Hirohata Works in 1993, the molten iron storage furnace with induction heater at Yawata Works in 1998,²⁵⁾ and the rotary hearth furnace (RHF)²⁶⁾ for the recycling of dust in 2000. In the meantime, the company has continually developed new refractory technology suitable for the new processes mentioned above. Thus, it may be said that refractory material technology really advances together with the development of new iron and steelmaking processes.

6. Change of Principal Refractory Technology at Nippon Steel

Table 2 summarizes the advances in principal refractory technology that Nippon Steel has achieved over the past 20 years in order to cope with the changes in the external environment and steel manufacturing equipment described earlier. Fig. 16 shows the change in the number of papers on new refractory technology over the two decades. As a technological trend in recent years, it may be said that as compared with technical reports on specific refractory materials, those on furnace construction and evaluation techniques, including recycling, are increasing in number.

When it comes to refractory technology, there is a tendency to attach importance only to refractory material technology that does not entail any investment in plant and equipment. Actually, however, all material technology has its limits. It should be said that in order to ensure stable operation of furnace equipment in the steel-

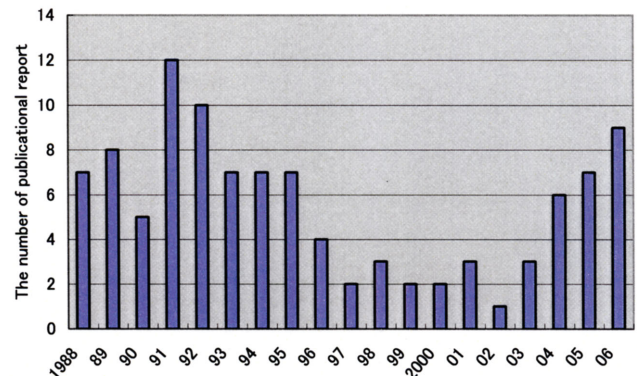


Fig. 16 Transition of the number of publication report on new refractories technology in NSC

Source of iron			Lump of mineral ore	Fine mineral ore		
Reducer				Pellet	Sinter ore	(apply to directly)
Coke	Coal as raw material	Caking coal	Blast furnace method			
	Slak coal	Lump of coal	Kiln method ex. (SN/RN)	Corex (hot metal)		
		Brequet coal				Finex (hot metal)
		fine coal		Fastmet Inmeteco		Hismelt (hot metal)
				ITmk3		(DIOS) (hot metal)
	Natural gas			Midrex HylIII		

Fig. 15 Classification of new iron-making process

Table 2 Progress of new refractois technology in NSC

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making process and ensure high quality steel, it is indispensable to make the most effective use not only of refractory material technology, but also furnace construction technology, repair and diagnostic technology, and recycling and evaluation technology.

Major achievements in the field of refractory materials over the past 20 years include: the blast furnace carbon block, unburned alumina-silicon carbide-graphite bricks,²⁷⁾ monolithic alumina-spinel castable material,²⁸⁾ alumina-graphite nozzles burned in a reducing atmosphere, and crystalline ceramic fibers for use at high temperature.²⁹⁾ Ironically, during the period 1994-2002 when crude steel production was very sluggish, imported raw materials for bricks and imported bricks themselves contributed much to the reduction of variable costs.

As major achievements in the field of furnace construction and mechanization technology, large-capacity flame gunning,³⁰⁾ the application of monolithic refractory and microwave drying,³¹⁾ equipment for building converters,³²⁾ and hearth separation may be cited. In terms of repair and diagnostic techniques, the dry spraying and rotary shotcrete method,³³⁾ laser profile meter, and miniaturized infrared thermometer are worthy of special mention.

Looking at refractory demolishing and recycling technology, the high-efficiency chipping machine,³⁴⁾ and the technology for crushing, magnetically separating, sorting and mixing refractory,³⁵⁾ play an important role. In particular, in the field of refractory ceramics R&D that deals with high-temperature molten substances, brick structural analysis using a rigid spring model,³⁶⁾ and brick evaluation and analysis techniques, such as the theoretical phase diagram, form the basis on which to determine quantitatively the governing factors in complicated phenomena that involve a solid-liquid mass transfer under high temperatures and a field of motion in which molten metal flows by agitation and to find clues to improvements. So far, such clues to improvements have been sought on the basis of a hypothetical mechanism for wear of refractory in use that was derived from a study of refractory before and after use. In the future, it is necessary to dynamically analyze the condition of wear of refractory in use by making effective use of advanced techniques.

7. Conclusions

Thus far, we have reviewed the progress of the refractory technology of Nippon Steel over the past 20 years. Amid the ever-increasing proportion of high-grade steels and dramatic changes in the refining processes and crude steel output, the company has steadily reduced specific refractory consumption and enhanced and maintained the international competitiveness of its refractory technology by effectively utilizing the results from development of new refractory materials and new technologies for furnace construction, repair, diagnosis, dismantling and recycling for the individual manufacturing processes.

In view of the rapid progress of the BRICs (Brazil, Russia, India, and China) in this particular field in recent years, in order for Nippon Steel's refractory technology to keep leading the world refractory market and to further enhance and maintain its international competitiveness, it is important to change its stance of operation management from the conventional follow-up type to a seeds-proposal one. Specifically, it includes:

- (1) Shifting from the proposal of consumable materials to the proposal of seeds that will lead to manufacturing process innovations
- (2) Formulating and executing measures to break away from an overdependence on China for raw materials for refractory (graph-

ite, magnesia, alumina, SiC, etc.)

- (3) Creating seeds for measures to protect the environment and save energy (in particular, heat insulation and recovery of low- to medium-temperature heat)
- (4) Securing the know-how and skills of furnace construction workers and simplifying and mechanizing (automating) construction and maintenance work
- (5) Improving the prediction accuracy for refractory life through development of systematic diagnostic technology and implementing scheduled refractory maintenance.

In order to carry out the above technical tasks speedily and positively, it is indispensable to retain a powerful workforce and foster able staff members. In this regard, it is considered necessary to enhance governmental-industrial-academic cooperation. In concluding this paper, we hope that it will be of help to young and mid-ranking researchers and engineers who are expected to shoulder the next generation.

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