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# Progress and Future Prospects of Steelmaking Technology

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## Abstract

***Steelmaking technology of Nippon Steel Corporation has evolved aiming at the following objectives: in steelmaking in general, maintaining cost competitiveness in the world market, responding to fluctuating demands and stable production of high-end steel grades; in refining, enhancement of environmental protection such as decreasing slag discharge to outside the works, lowering $CO_2$ emission and intensive dust collection; and in continuous casting, incorporating desired high quality in slabs/blooms of difficult-to-produce steels at high productivity. This paper outlines the past technical developments in the entire steelmaking and individual processes and field operation improvements, and provides future prospects for the steelmaking industry.***

## 1. Introduction

The last special edition on steelmaking technology of the then Shinnittetsu Giho (Nippon Steel Technical Report) was published in 2012 that described the progress and future prospects of steel refining and continuous casting technologies.[1, 2] Seven years have passed since then and the environment of the steel industry has changed remarkably in the interim. The world's crude steel production has expanded: China's steel output has increased year after year backed by vigorous domestic demand mainly for general-purpose steel to exceed 900 million tons per year (Mtpy, all the units herein are metric), and the steel production of India has grown to over 100 Mtpy, surpassing that of Japan in 2018, making the country the second largest steel producer of the world.[3] In the competition with overseas emerging mills having large production capacities, it is increasingly necessary for Japanese steelmakers to cut manufacturing costs. In the automotive field, the users' requirements for high-strength steel are increasing for body weight reduction in response to tightening environmental regulations.[4] In the sector of heavy steel plates, increasingly larger and more complicated structures are being built in tougher environments, and consequently the demand for better low-temperature toughness and ultra-heavy plates is increasing[5] as well as that for higher strength.

Against this background of changes in the business environment, Nippon Steel Corporation and Sumitomo Metal Industries, Ltd. merged in 2012 to form Nippon Steel & Sumitomo Metal Corporation (the trade name was changed to Nippon Steel Corporation in 2019). Since then, it has become possible to combine the expertise that had been fostered separately by each of them and disseminate it company wide. It also became possible to develop technology through company-wide activities of the steelmaking divisions of all the works as well as the central and works-based steelmaking research laboratories. The present report describes the changes in steelmaking technology including new developments achieved by the synergistic effects of the merger.

## 2. Changes in Steel Refining Technology

In the steel refining process, in addition to the increasing need for high-end products described above, the refining load is increasing owing to the increase in impurities in hot metal because of the lowering quality of the raw materials. In this situation, technical development has concentrated on the stable production of high-grade steels at high efficiency and low cost, while suppressing the slag generation. This report presents the changes in steel refining technology in this respect and future prospects.

### 2.1 Responding to problems in steel refining process

The development of steel refining technology over the last few years has focused on the following four issues: (1) to review the hot metal pretreatment process, that is, to separate desiliconization, desulfurization, dephosphorization and decarburization of hot metal from each other, reduce the costs of reactive agents used for these processes by improving process efficiency and decrease slag output; (2) to increase thermal allowance, maintain the high hot metal pretreatment ratio and enhance the freedom of choice of raw materials; (3) to meet the recent demand for higher steel strength, workability

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and toughness as a reliable supplier of high-end products; and (4) to promote energy saving and environmental measures such as the suppression of carbon dioxide emission and prevention of dust emission from plant buildings, while maintaining a manufacturing structure with high productivity.

Through technical development in the pursuit of the above targets, the converter-type processing has become the main stream of hot metal dephosphorization, and in the field of secondary refining, measures have been taken to secure capacity of the degassing facilities to meet the requirements of different product types, and processes to remove impurities and nonmetallic inclusions have been developed. In addition, since the establishment of Nippon Steel & Sumitomo Metal, various synergistic effects have been realized through the cross introduction of technologies of the former two companies. The changes in the different technical fields of steelmaking are described below from these viewpoints. **Table 1** shows the changes in refining technology over the last few years.

**2.2 Separation of refining functions**

2.2.1 Outlines

By the 1980s, Nippon Steel had established a divided steel refining process, whereby, as the pretreatment before decarburization, hot metal was desiliconized, desulfurized and dephosphorized using torpedo cars (hereinafter referred to as TPC), hot metal ladles or converters as the reaction vessels.[6] The challenges and technical developments thereafter include the separation of hot metal desulfurization from dephosphorization, that of dephosphorization from decarburization, development of a fluorine-free dephosphorization process using the converter as the reaction vessel, improvement of reaction efficiency in these processes, slag recycling, controlled desiliconization of high-Si hot metal and increase in the converter capacity for dephosphorization.

2.2.2 Hot metal desulfurization

Desulfurization is a reduction reaction, its efficiency decreases in an oxidizing atmosphere, which is adequate for dephosphorization, and for this reason, the former was separated from the latter for higher refining efficiency.

For hot metal desulfurization, Nippon Steel employs the injection method[7] using CaO-Mg flux with high desulfurizing ability and the Kambara Reactor (KR) method[8] with high efficiency owing to mechanical stirring, and either of the two is employed at each of the steelmaking plants according to the condition of the production equipment. In addition, taking advantage of the effect to accelerate the reaction by the addition of Al[9], which is more economical than Mg, CaO-Al flux is also used for the injection process, in consideration of the sulfur content required for the products.

As a result of the separation of the hot metal desulfurization from dephosphorization, it became possible to desulfurize hot metal at high temperature immediately after discharging from a TPC or a ladle, and the process efficiency has been improved. In addition, it is now possible to separate and recover desulfurization slag and recycle it for the iron ore sintering process; this is commercially practiced at most works of the company.

2.2.3 Separation of hot metal dephosphorization from decarburization

The conventional hot metal pretreatment method using TPCs or hot metal ladles as the reaction vessel enabled stable production of low-phosphorus and low-sulfur steel, but it deprived the thermal allowance for the decarburization process in the converters, and re-

Table 1 Problems in steel refining process and solutions

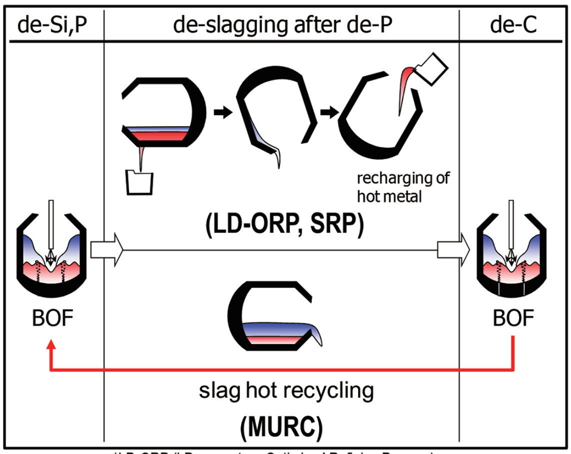
| Year | Topics (Raw materials / Heat recovery / Production / Energy saving / Environment) | Process solutions (De[S] / De[P] / De[C] / Secondly refining) |
|---|---|---|
| | | ・Start up of LD-ORP(Nagoya) |
| 1990 | | |
| | ・OG boiler (Kimitsu) | ・Renewal of the control system [DDC] |
| | | ・Start up of REDA(Yawata) |
| | ・Start up of Scrap Melting Process (Hirohata) | |
| | | ・Start up of MURC process (Muroran) |
| | | ・Mass production of IF steel |
| | | ・High speed decarburization |
| | | ・Applying AC to de-C (Hirohata) |
| | ・Iron Reserve Barrel (IRB, Yawata) | |
| 2000 | ・OG boiler(Oita) | ・Desulfurization by injection in the ladle(Oita) |
| | ・Regulation of Fluorine in the soil | ・Desulfurization by KR in the ladle(Kimitsu,Yawata) |
| | | ・Separation of desulfurization process |
| | ・Reinforcement of converter dust collector | ・Increase of converter type dephosphorization (Without Fluorine) |
| | ・Decrease of HMR ・Increase of converter working rate | ・Additional LF(Muroran) |
| | ・Scrap Melting in torpedo ladle ・Increase of converter heat size | ・High speed operation of MURC process |
| | ・Converter without Fluorine | ・High speed blowing in converter [nozzle improvement] |
| | ・Shredder machine(Nagoya, Oita) ・Shortening of converter cycle time | |
| | ・Decrease of the heat conductivity of torpedo ladle refractory | ・New dephosphorization furnace(Kimitsu) |
| | ・Increase of the torpedo ladle turn over | ・New decarburization furnace(Nagoya) ・Additional RH (Nagoya, Kimitsu) |
| | ・Dust recycle by RHF,DSP (Kimitsu, Hirohata, Hikari) ・Increase of LDG recovery | ・New desulfurization furnace(Nagoya) |
| 2010 | ・Reinforcement of dust collector at the ceiling | ・Increase of RH treatment (Oita, Kimitsu) |
| | ・EAF for stainless steel(Yawata) | ・Promotion of slag recycle |
| 2012 | Merger between Nippon Steel and Sumitomo Metal | ・Promotion of pretreatment |
| | | ・Application of AC(Kimitsu2) |
| | | ・Improvement of de-S with Al ・High speed blowing in converter [nozzle improvement] |
| | ・Restructuring of production in Kimitsu (Converter operation form "2 of 3"⇒"1 of 2" at Kimitsu1) | ・Start up of MURC(Kashima2) |
| | | ・Increase of vacuum pumping system(Yawata) |
| | | ・Application of AC(Kimitsu1) ・Start up of LF(Yawata) |
| 2020 | | |

stricted the charging amount of scrap steel.[6] On the other hand, the converter has a large freeboard, is capable of high-speed dephosphorization under strong bath agitation by oxygen gas blowing, and in addition, has a high scrap melting capacity. To solve the above problem of thermal allowance, different types of new dephosphorization methods using the converter as the reaction vessel have been developed at different works according to the condition of related facilities, and commercially applied.

One of such methods is the LD-optimized refining process (LD-ORP) first introduced to the Steelmaking Plant of Nagoya Works in 1989.[10, 11] By this method, hot metal is charged into a converter used exclusively for hot metal pretreatment, desiliconized and dephosphorized mainly by blowing oxygen gas taking advantage of the large freeboard not available in TPCs, and then after deslagging, it is decarburized in another converter exclusive for the purpose. Although the hot metal has to be transferred between converters, the method is capable of decreasing CaO consumption, improving yield and stable, high-speed processing. After its commercial application at Nagoya Works, Kimitsu, Yawata and Muroran Works introduced the process to produce ultra-low phosphorus steel (see **Fig. 1**[12])).

Another method, the multi-refining converter (MURC) process, consists of dephosphorization and decarburization performed sequentially in one converter under oxygen blowing, with intermediate deslagging in between.[13–15] This process uses the strong metal bath agitation and high-speed oxygen blowing of the converter to efficiently dephosphorize under a high oxygen potential and a low $CaO/SiO_2$ (hereinafter referred to as basicity) of the slag. The dephosphorization of a succeeding charge is carried out using the decarburization slag of the previous charge left in the vessel; this makes it possible to conduct the two processes with minimal heat loss, and a significantly reduced amount of slag (see Fig. 1[12])).

However, since dephosphorization and decarburization are performed continuously in the same converter by the MURC process, the processing time was long at the beginning, and for application to mass production plants, the processing time had to be shortened. Eventually, the cycle time was shortened to roughly 35 to 37 min. On the other hand, in terms of CaO consumption, slag generation and effective use of thermal allowance, this method was very efficient for producing steel for general applications (except for ultra-low phosphorus steel). In appreciation of this, after its development at Muroran, it was widely introduced to Oita, Kimitsu, Yawata and



*LD-ORP (LD converter - Optimized Refining Process)
MURC (Multi Refining Converter) SRP (Simple Refining Process)

**Fig. 1 Converter type hot metal dephosphorization processes**[12])

other works. Furthermore, as a synergistic effect of the merger of the former Nippon Steel and the former Sumitomo Metal Industries, it was introduced to the No. 2 Steelmaking Plant of Kashima Works.

The simple refining process (SRP),[16] commercially practiced at the No. 1 Steelmaking Plant of Kashima Works, Wakayama Works and the Kokura Area of Yawata Works, is the same as the LD-ORP in terms of the process flow, and is characterized by high-efficiency dephosphorization thanks to very strong bath agitation by bottom gas blowing through single annular (SA) tuyeres backed by high-pressure gas facilities.

Fluorine regulations were introduced to the environmental standards for soil in the 2000s, and the development of a fluorine-free dephosphorization process was encouraged. By the conventional hot metal dephosphorization in TPCs and hot metal ladles, because of the limited vessel capacity, it was necessary to restrict the amount of slag and raise its basicity using fluorine, and without it, the processing efficiency was significantly lowered. Against this background, the converter type hot metal dephosphorization process became widely employed, whereby the metal bath is dephosphorized using a large amount of low-basicity molten slag in a large-capacity vessel without requiring fluorine.

Thus, since the 1990s, hot metal pretreatment methods making the most of the advantages of the converter rapidly expanded, and as a result, the LD-ORP, the SRP and the MURC process, all of which use the converter as the reaction vessel, replaced the conventional dephosphorization in TPCs or hot metal ladles, and became the mainstream of hot metal pretreatment.

Soon after the merger into Nippon Steel & Sumitomo Metal, the ratio of hot metal pretreatment was as low as approximately 80% in the whole company, partly because it was not conducted at the No. 2 Steelmaking Plant of Kashima Works, but after the plant introduced the MURC process and applied it to all heats, the ratio increased to roughly 95%. Efforts will continue to raise the efficiency of the converter dephosphorization reactions as well as to enhance the process efficiency aiming at raising the hot metal pretreatment ratio to 100% in the whole company.

2.2.4 Hot metal desiliconization

High silicon concentration in hot metal from blast furnaces leads to an increase in the CaO consumption in steelmaking and a consequent increase in the amount of slag discharged, causing large loads on the environment. Low slag generation was required for dephosphorization in TPCs or hot metal ladles because of the limited capacity of the reaction vessels. Conventionally, the silicon content of hot metal was lowered first through desiliconization, and after discharging the slag, dephosphorization was performed using fluorine and high-basicity and high-melting point slag.[17] As stated earlier, when the hot metal dephosphorization in the converter was adopted, desiliconization and dephosphorization were possible in a large reaction vessel using slag of a relatively low basicity and low melting point and without using fluorine. It was not necessary, therefore, to minimize the Si content in hot metal. There is, however, a certain Si content range appropriate for dephosphorization, and it was decided that, when the Si concentration in hot metal exceeded the appropriate level, it should be lowered before dephosphorization. In recent years, however, as shown in **Fig. 2**, the desiliconizing capacity is insufficient owing to the rise in the silicon content in hot metal, and the use of this technology is expanding to decrease the slag formation and raise the molten steel yield, etc. Desiliconization in TPCs is being expanded; a new facility was commissioned at Nagoya Works in 2018, and another is scheduled to start up at Oita Works in 2020.

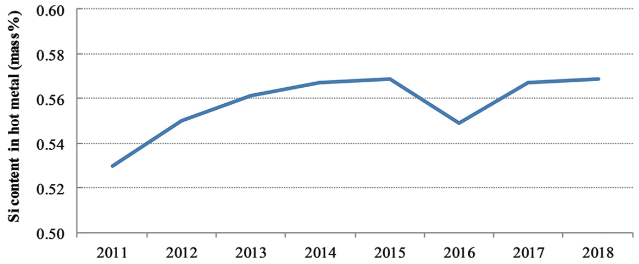



**Fig. 2 Change of Si content in hot metal**

| Works | Separation of refining processes | | | |
|---|---|---|---|---|
| | De[Si] | De[S] | De[P] | De[C] |
| Muroran | Torpedo ⇒ | Torpedo (De[S] in LF) ⇒ | Converter ⇒ LD-ORP MURC | Converter |
| Kashima | Ladle (in charging) | Ladle KR | Converter ⇒ SRP MURC | Converter |
| Kimitsu | Torpedo ⇒ | Ladle KR Partially Torpedo ⇒ | Converter ⇒ LD-ORP MURC | Converter |
| Nagoya | Torpedo 2018~ ⇒ | Converter Desulfurization Furnace ⇒ | Converter ⇒ LD-ORP | Converter |
| Wakayama | Ladle (in charging) | Ladle KR | Converter ⇒ SRP | Converter |
| Yawata (Kokura) | | Ladle KR | Converter ⇒ SRP | Converter |
| Yawata (Tobata) | Torpedo ⇒ | Ladle KR Injection ⇒ | Converter ⇒ MURC Partially Torpedo | Converter |
| Oita | Torpedo ⇒ | Ladle Injection ⇒ | Converter ⇒ MURC Partially Ladle | Converter |

**Fig. 3 Separation of refining processes in Nippon Steel**

As a result of separating the four main steel refining processes, namely desiliconization, desulfurization, dephosphorization and decarburization from each other, the efficiency of the reactions has been improved. Measures have been taken in parallel to further cut the costs by classifying, recovering and recycling the slag generated from these processes and decreasing its discharge to outside the system. **Figure 3** shows the hot metal pretreatment processes at different works of the company; the works aim to adequately separate the four processes in consideration of the features of their related facilities.

2.2.5 Increasing slag recycling and decreasing slag discharge to outside works

The slag forming during decarburization has a comparatively high basicity; it is hot under the converter blow-end condition, and the concentration of phosphorus oxide is low. By reusing it for hot metal dephosphorization, which proceeds at a lower temperature, it is possible to decrease the CaO consumption and cut the costs. For this purpose, the decarburization slag is separately collected and recycled for dephosphorization. By the MURC method, the decarburization slag is solidified in the converter and used for the dephosphorization of a succeeding charge; this slag hot recycling is being implemented at many works. When the amount of the decarburization slag is excessive, it can be recycled to the iron ore sintering process. The recycling of decarburization slag is possible only when dephosphorization of hot metal is performed as a separate process and the decarburization and dephosphorization are separated from each other. In addition, the concept of decreasing the CaO consumption by recycling the high-basicity slag to a low-basicity process can be applied to hot metal desiliconization in TPCs; actually, this is being done at Oita and other works.

As explained above, Nippon Steel has reduced the amount of slag discharged to outside the works by increasing the ratio of hot metal dephosphorization, recycling the decarburization slag and controlled desiliconization of hot metal.

2.2.6 Promotion of refining reaction analysis using mathematical models

In the steel refining process, the oxidation and reduction reactions of Si, Mn and Fe proceed simultaneously in parallel to desulfurization, dephosphorization or decarburization. A variety of reaction calculation models have been developed over the last few years to analyze and optimize the process. Nippon Steel has developed a comprehensive reaction analysis model named the Mathematical Analysis Codes for Slag-metal Reaction and Injection Metallurgy (MACSIM)[18] based on a coupled reaction model[19] and used it for operation analysis. On the other hand, in the dephosphorization reactions, the distribution of phosphorus between the solid and the liquid phases of the slag is affected by the iron oxide concentration in it.[20] Based on this fact, a study team of the Iron & Steel Institute of Japan has constructed a multi-phase calculation model to calculate the mass transfer in the solid and liquid phases of the slag and the metal phase based on the coupled reaction model.[21, 22] In the current converter dephosphorization operation, the dephosphorization rate is improved by optimally controlling the iron oxide concentration in the slag in the middle stage of the process according to the results of multiphase slag analysis.

Regarding the thermodynamic model for calculating the state of equilibrium attained at the end of the refining reactions, a general-purpose thermodynamic calculation model has been made available and is playing an important role in the basic R&D studies on the plant floor. This model is based on the cell model developed mainly by the Advanced Technology Research Laboratories of Nippon Steel jointly with IRSID;[23, 24] it makes use of a large number of thermodynamic databases accumulated over the years. However, estimation accuracy is not sufficiently high in relation to some element systems, and further development is expected to enhance their databases.

Calculation accuracy of heat and mass transfer in various processes has been improved. Simulation analysis by numerical calculation is now widely employed for plant floor operation and development studies. Calculation accuracy is also now sufficiently high for the analysis of the oxygen jet of the converter blowing (to be described later), the quantitative analysis of dust generation during the hot metal charging into the converter and the dust concentration in the exhaust gas after that.

In addition, it is now possible to obtain the rate of decarburization reactions from the analysis values of CO and $CO_2$ in the exhaust gas. An exhaust gas dynamic model has been developed recently;[25] it exhibits a high estimation accuracy based on decarburization reaction rate coefficients calculated from the above, and the estimation accuracy of the carbon content in molten steel at the converter blow end has been improved (see **Fig. 4**).

### 2.3 Enhancement of converter productivity

2.3.1 Backgrounds

Dephosphorization of hot metal in the converter was targeted because of the fluorine regulations as stated above, and as a result,

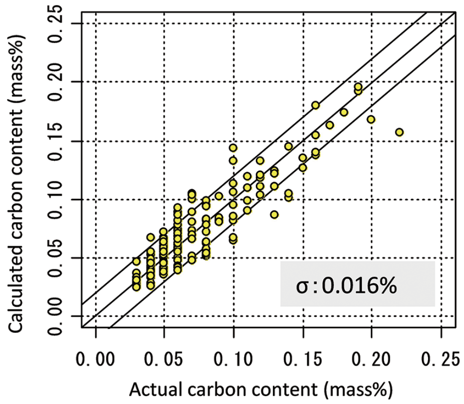



**Fig. 4 Accuracy of carbon content estimation**

the thermal allowance has become larger than by dephosphorization in TPCs or hot metal ladles. As a result, it became possible to lower the hot metal ratio (HMR) of the converter and dephosphorize hot metal while melting more scrap steel. On the other hand, as a result of the dephosphorization in the converter, part of the converter operating time was used for it, and the productivity decreased especially with the converter in the MURC operation. Moreover, after the shutdown of the No. 3 Blast Furnace at Kimitsu Works at the end of the fiscal year (FY, from April to March next year) 2015, the No. 2 Converter of the Kimitsu No. 1 Steelmaking Plant was shut down, and the operation mode of the converters changed from 2/3 to 1/2 vessels. For this reason, productivity improvement of the converters became a major issue especially at Kimitsu Works.

It was necessary to drastically increase the converter capacity to solve the problem, and measures were taken focusing on three points: increasing the heat size, improving the operating ratio and shortening the cycle time. They are explained below in more detail.

2.3.2 Increase in converter capacity

Regarding the increase in the heat size, it was executed when the ladles were enlarged after the converter shells were replaced with larger ones at the time of periodical renewal and the cranes of the downstream processes were also enlarged at the timing of the renewal.

To raise the operating ratio, the non-production time has been cut by measures such as the introduction of hot and cold refractory spraying machines and slag splash coating facilities to shorten the repair time, installation of quick tap-hole repair machines to reduce the hole brick replacing time and the provision of special lances to quickly remove the sculls from the converter nose.

On the other hand, with regard to shortening the cycle time, it was intended to shorten the blowing time mainly by increasing the oxygen blowing rate during decarburization. With the increasing hot metal pretreatment ratio, the need especially for a shorter blowing time has been on the rise in recent years, and the importance of improving the lance nozzle design and the blowing pattern is increasing in terms of the oxygen blowing rate and the lance height.

Particularly when the oxygen blowing rate is increased, dust generation increases, and the steel yield is lowered. In consideration of this situation, two types of lance tips were developed: one of them[26, 27] was capable of suppressing the dynamic pressure of the oxygen jet on the bath surface taking advantage of the expansion characteristics of the supersonic jet; and the other[28] suppressed spitting by controlling the peak position and the distribution of dynamic pressure by tilting the nozzles in the circumferential direction as

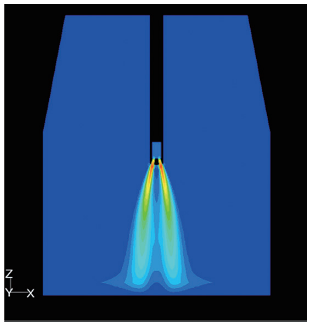



**Fig. 5 Example of the calculation result of top blown jet**

well as in the direction of the converter radius. As a result of these measures, the blowing technology has been improved to achieve both high-speed oxygen blowing and lowering dust generation. Thanks to the remarkable advance of numerical analysis over the last few years, the time for the development of these lance tips was shortened by a new design method, where the characteristics of the oxygen jet were predicted using numerical analysis (see **Fig. 5**).

2.3.3 Advances in converter refining technology

(1) Converter top blowing

As written above, new types of top blowing lances have been developed aiming at raising the oxygen blowing rate while minimizing dust generation during decarburizing. As for dephosphorizing blowing, on the other hand, the processing efficiency has been improved through modification of the LD-Arbed CNRM (LD-AC) method, whereby fine quick lime is blown with oxygen through the blowing lance to accelerate the dephosphorizing reactions. The method exhibits a high dephosphorization accelerating effect.[29] Although Kimitsu Works did not employ this method for long, it was introduced lately to its No. 1 and No. 2 Steelmaking Plants to facilitate the production of steel grades with high dephosphorization loads.

(2) Bath agitation in converter by bottom blowing

Regarding the method of bath agitation in the converter by bottom blowing, the former two companies before the merger separately developed their own methods. The former Nippon Steel developed LD-oxygen bottom blowing (LD-OB), by which part of the oxygen was blown in from the bottom, LD-$CO_2$-bottom bubbling (LD-CB), by which inert gas was blown in from the bottom and LD-powder bottom blowing (LD-PB), by which flux powder was blown in from the bottom. The former Sumitomo Metal, on the other hand, developed LD-Sumitomo top and bottom blowing (LD-STB), by which high-pressure inert gas was blown in at a high flow rate. All these methods were developed by the end of the 1980s and commercially applied at different works according to their features.[1, 16]

At the works of the former Nippon Steel, in appreciation of the strong bath agitation ability, the LD-OB was introduced to Yawata Works, Nagoya Works (limited to the decarburizing converter), Kimitsu Works (limited to the No. 2 Steelmaking Plant) and Oita Works. The LD-CB was introduced to the Kimitsu No. 1 Steelmaking Plant and Muroran Works, because of the need for decreasing the flow amount of the bottom blowing gas during decarburization for the sake of the requirement for high end-point carbon for the assigned steel grades . Hirohata Works has been using the LD-CB for the decarburizing furnace of the cold iron source melting process (to be explained later). The LD-PB method is applied to the ORP furnace of Nagoya Works because of its advantages for dephosphorization.[6] The LD-STB is applied to all the converters of the former Sumitomo Metal works; as described earlier, the SA tuyere with high-pressure gas equipment is characterized by a wide control range of gas flow from very strong agitation by large gas flow to weak stirring by low gas flow.

Whereas by the LD-OB method the bottom-blowing gas flow rate is currently 0.15 to 0.20 $Nm^3$/t/min, by the LD-STB, it can be increased up to roughly 0.35 $Nm^3$/t/min, and when strong agitation is required, this method is more advantageous. On the other hand, the LD-OB method uses a double-pipe nozzle for bottom blowing oxygen through the inner pipe and cooling gas through the outer, and thus is capable of simultaneous oxygen blowing and cooling with a very low rate of nozzle erosion.

(3) Improvement of refining accuracy by sensing

Development has been made to improve the refining accuracy by obtaining information of the inside condition of the converter. Microwave level meters were introduced to quickly detect the surface level of the metal bath, and it became possible to measure the distance between the lance tip and the molten metal surface without using the sub-lance; this enabled frequent distance measurement and improved the refining accuracy.

Different from the above, predicting the timing when the lance tip is dipped into the surface of the foamed slag has been enabled by sensing a decrease in the sound pressure with sound pressure sensors.

Laser profile meters have been installed at positions fixed relatively to the converter to detect the erosion of its refractories. Local wear of the refractories is detected by rapid and frequent measurement, and the efficiency of repair has been improved.

Furthermore, an exhaust gas dynamic model has been developed that incorporates the measured values of exhaust gas analysis by conventional sensing technology into a dynamic control model.

Thanks to these sensing technologies, converter blowing operation has been stabilized, damage to converter refractories reduced and operational problems decreased. In addition to the converter operation stabilization effect by the hot metal dephosphorization, the accuracy of dynamic blowing control based on the temperature measurement and sampling by the sub-lance at the end of blowing has been improved, and as a result, it is now possible to tap the steel immediately after the blow-off without the final temperature measurement and sampling; the operation mode is internally called the “one sub-lance per charge operation”.[30]

### 2.4 Improvement of secondary refining functions

#### 2.4.1 Expanded application of degassing

Conventionally, the need for degassing was limited to dehydrogenation of the molten steel for some heavy plate products. Cold-rolled sheets for automotive applications, however, began to be produced through continuous annealing, and as a result, Nippon Steel’s production of steel grades requiring vacuum decarburization such as interstitial-free (IF) steel increased rapidly. In addition, as steel sheets for automobiles became wider and continuous casting speed was raised, it became necessary to shorten the processing time of secondary refining, and technical improvements were made to shorten the decarburization time. To shorten the processing time of the Ruhrstahl-Heraeus (RH) vacuum degasser, elemental technologies have been developed that include increase in the circulation flow by increasing the diameters of the snorkels, the amount of circulating gas and the capacity of the vacuum exhaust system. In particular, with the aim of shortening the vacuum-achieving time at the start of the processing, a method called the preliminary vacuum method has been introduced widely, whereby the processing tank is separated from the evacuation system and the air is exhausted from the latter in advance.[31]

The vacuum pumping system itself has been upgraded by introducing a high-performance booster and ejector and combining them with a high-efficiency mechanical pump. RH degassers with such a high-performance vacuum pumping system were installed at Nagoya Works (No. 3 RH) in 2007 and at Kimitsu Works (No. 3 RH) in 2010[32]; they have shortened the process time and enabled mass production of IF steel. The capacity increase of the degassers has made it possible to improve the operation synchronization with continuous casters, and realized the effect of reducing carbon contamination through sequential treatment of ultra-low carbon steel in the same RH unit. In addition, various decarburization models have been constructed and commercially applied to prevent excessive decarburization by calculating the process end timing.[33]

Some RH degassers are equipped with multi-function burners (MFB) for oxygen top blowing for decarburization and heating during the processing and heat retention of the processing vessel: a lance is inserted into the vessel and fuel and oxygen are blown through it. By this, it is possible to keep the vessel hot both during vacuum processing and at atmospheric pressure, and blow oxygen for aluminum heating during the processing as well. The heat retention of the vessel reduces the scull deposit on the vessel wall, and contributes to shortening the processing time of ultra-low carbon steel. As a result, it became possible to lower the blow-end temperature of the converter.[34,35]

Nippon Steel operates another type of vacuum degasser, the revolutionary degassing activator (REDA). By this process, the degassing process proceeds continuously and efficiently by sucking molten steel upward into a processing vessel through one large-diameter snorkel, and accelerating refining reactions by strongly agitating the steel bath with gas bubbling from the ladle bottom. It was developed on the basis of the Dortmund-Hörde (DH) degasser, and is characterized by much higher processing efficiency than by the cyclic reaction process of the original DH degasser. The DH degassers of the Tobata Steelmaking Plant of Yawata Works and the No. 1 Steelmaking Plant of Kimitsu Works were replaced by REDA by 1997.[36] No. 2 REDA was installed at Tobata in 2007 to cope with the production increase of steel grades requiring degassing. Initially, the vacuum exhaust system was common to Nos. 1 and 2, but a second system was added in 2018 to meet increased processing demand, and the two are operating as independent degassers at present.

It has to be noted that, as a result of the sequential RH treatment, the temperature of the vacuum processing vessel is maintained high, the RH refractory costs have been lowered and lowering of the converter blow end temperature has been enabled. In consideration of the advantages, expanded application of light RH treatment to general-purpose steel grades has been encouraged; at Oita and Kimitsu Works, where the RH treatment capacity is balanced with the converter capacity, 100% RH treatment is envisaged.

#### 2.4.2 Role of CAS-OB

Conventionally, steel tapped from the converter underwent deoxidation and composition adjustment by gas bubbling in ladles. As a simple secondary refining method that replaces this processing, the composition adjustment by sealed argon bubbling-oxygen blowing (CAS-OB) became widely used for steel grades not requiring degassing treatment. Recently, wider application of RH treatment is envisaged, and as the ratio of RH light treatment has increased accordingly, that of CAS-OB treatment has decreased. In particular, at

Oita Works, 100% RH treatment has been achieved, the use of porous plugs for gas bottom bubbling has been discontinued and currently the CAS-OB treatment is not applied.

2.4.3 Installation of additional LFs

Nippon Steel does not use ladle furnaces (LF) to shorten the time of secondary refining of steels for general applications, but they are employed for steel grades requiring extremely low oxygen contents and those for bars, wire rods, heavy plates of special steel and high carbon steel for which steel heating is indispensable. At Muroran Works, in response to the need for stricter inclusion control for special steel, a second LF was built to enable LF processing of all heats.

At the Tobata Steelmaking Plant of Yawata Works, to reduce the load on the converter in the production of high-carbon steels for rails and machine structure, the tapping temperature of which is high, and to supply steel for bars and wire rods to the Kokura Area after the closure of the upstream facilities there, an additional LF was built and put into operation in 2018.

2.4.4 Stable production of high-purity steel

Demand has been increasing for high-end steel materials such as ultra-low-P, low-S and sour-resistant pipes, low-S and high-tensile thin sheets and low-P and low-S heavy plates, and in response, technical development has been encouraged to enable mass production of high purity steel.

(1) Ultra-low-phosphorus steel

Ultra-low-P steel can be stably produced by the converter-type hot metal dephosphorization process, the LD-ORP or the SRP method, or by hot metal dephosphorization in TPCs or hot metal ladles. It is possible to satisfy an upper limit P content standard of 54 ppm.

(2) Ultra-low-sulfur steel

Various molten steel desulfurization processes have been developed for the stable production of ultra-low-S steel: these include the RH injection[37)] and the RH-powder top blowing (RH-PB)[16)] methods, which are applicable during RH degassing, and the Kimitsu injection process (KIP), whereby desulfurizing flux is blown into steel in a ladle.

By the RH injection method, the flux is blown into the up-leg snorkel of the RH degasser through a J-shape refractory lance during the treatment, and degassing and desulfurization are performed at the same station. By the RH-PB method, on the other hand, steel is desulfurized by blowing the flux from above during the RH treatment. By the KIP method, the flux is blown into molten steel in a ladle through a refractory lance. Kimitsu Works developed the KIP and the V-KIP methods; the latter is a variation of the KIP conducted in a vacuum vessel.[38)] It is possible by these methods to stably produce ultra-low-S steel to an upper limit S content standard of as low as 7 ppm. These desulfuring methods had been established as multifunctional secondary refining processes by the end of the 1990s.[1, 16)]

The Iron and Steel Institute of Japan has followed the changes of the upper limit contents of impurities in the relevant standards every 10 years.[39)] All Japanese steelmakers had developed P and S removal methods of their own to satisfy the standards by the end of the 1990s.

### 2.5 Advances in stainless steel manufacturing technology

Nippon Steel manufactured stainless steel at Yawata and Muroran Works; by the process, ferrochrome was melted in hot metal in a converter, and after rough decarburization, finishing decarburization is performed later during degassing treatment. When the continuous hot rolling mill of Muroran was closed in 1987, the stainless steel production was concentrated at Yawata Works. At the beginning, Yawata used the vacuum oxygen decarburization (VOD) process for the finishing decarburization, but after the REDA was developed, in appreciation of its high degassing efficiency and low nitrogen absorption, it was applied to the decarburization of molten stainless steel.[40)]

In 2010, an electric arc furnace was installed at Yawata Works for the production of stainless steel by melting ferrochrome and stainless steel scrap into high-chromium molten metal. The high chromium melt is then mixed with molten iron, and decarburized in a converter. The electric arc furnace also has the function of reducing unreduced converter slag having a high chromium oxide content, which made it possible to use economical ferrochromium and stainless steel scrap arising from inside the works as well as to minimize the discharge of chromium resources to outside. In appreciation of the above utilization of chromium resources, this process received the highest prize of the Okochi Memorial Production Special Prize at the 64th Okochi Prize Award in FY 2017.

### 2.6 Automation and labor saving

Many of the control facilities for the steelmaking process that were installed along with the plants around 1970 were already aged in the 1990s, and their renewal was required. Control devices employing the direct digital control (DDC) technology, then newly established, were introduced at their renewal, and the operators' rooms for hot metal pretreatment stations, converters and secondary refining facilities were concentrated in the respective areas. The number of operators is, basically, three per shift for a converter, and one per shift for each of the secondary refining facilities.[41)]

In recent years, DDC control devices have been combined with high-accuracy end point prediction technology based on the refining reaction analysis using the calculation models, and it has become possible to control the refining processes in a manner similar to conventional control based on operators' intuition. Further improvements are being developed with a view to future automation.

### 2.7 Recycling of steelmaking dust

The dust generated from the steelmaking processes was once recycled only to the converter process, but its reuse has been diversified as new processes were developed. At the Kimitsu, Hirohata and Hikari Area of Yamaguchi Works (transferred to Nippon Steel Stainless Steel Corporation), the dust is reduced using rotary hearth furnaces (RHF): at Kimitsu in particular, the dust arising from inside the works premises is reduced and divested of zinc using three units of RHF, and then recycled to the iron making process. In the Hikari Area, stainless steel dust is reduced in a RHF and reused as a raw material for an electric arc furnace. **Figure 6** illustrates the RHF process of Kimitsu Works.

At Hirohata Works, a cold iron source melting method, the scrap melting process (SMP)[42)], is commercially practiced, and after the blast furnace was shut down in 1993, a new process to produce molten iron was established, by which scrap iron purchased from outside and iron sources arising from inside the works including dust were melted and then refined in a conventional converter. Later, another process was developed, by which hot briquetted iron (HBI) manufactured through the RHF route is melted by the SMP, and the ratio of the dust in the charging materials for the SMP has increased ever since. However, the production cost of this process is high, and because of the poor competitiveness of the iron produced, a plan is being studied to switch the present SMP using a melting furnace and a converter to the electric arc furnace process, which is more energy efficient and flexible in production.

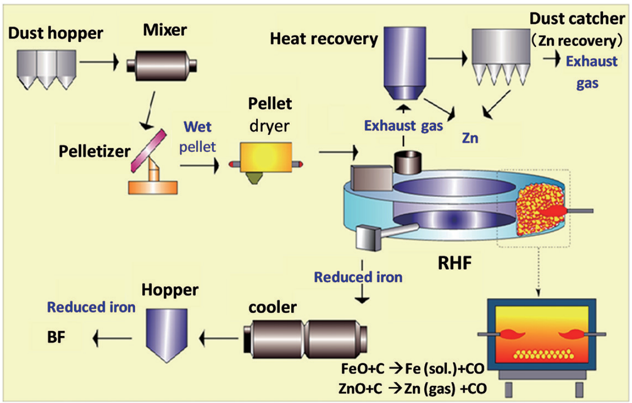



Fig. 6 Example of RHF process flow (Kimitsu Works)

### 2.8 Measures for energy saving and environmental harmony

2.8.1 Energy saving measures

To reduce energy costs and carbon dioxide emission, Nippon Steel has taken energy saving measures and increased the recovery of steam and LD gas (LDG). Regarding the oxygen converter gas recovery (OG) system, aged converter hoods have been replaced with OG boilers at the timing of their renewal.[43] The OG boilers have been installed at the main steelmaking plants of the company to achieve steam recovery exceeding 80 kg/t-steel. With regard to LDG, efforts have been made to increase its recovery by operational measures such as an early start of gas recovery based on quick gas analysis.

Dust collectors driven by large motors are mostly kept running at a constant rate, but the necessary air volume changes according to the operating condition of the related process. In consideration of this, the variable voltage variable frequency (VVVF) control has been introduced to adequately control the air volume and reduce the power consumption.

2.8.2 Measures to minimize dust emission from plant buildings

When production increase was required and the HMR of the converter was lowered and the scrap ratio was increased accordingly in the early 2000s, measures were taken to reduce the dust emission from the plant buildings. There were cases where all the dust generated during hot metal charging into the converter could not be caught by the primary dust collector of the OG system and the local dust collector of the furnace hood, and as a countermeasure, providing a dust collector covering an entire plant building was studied. At that time, the amount of air required for collecting the dust arising from the converter and the building inside was calculated based on flow simulation of the gas and dust inside it. When the system started up, the calculated dust concentration was found to agree sufficiently well with that actually measured, and thereafter, the building and local dust collectors were designed by this method.[44, 45] At present, a local dust collector is being installed in the Steelmaking Plant of Muroran Works to suppress the emission of red smoke according to the result of the simulation in which building one is not necessary.

### 2.9 Approach to future steel refining technology

The special issue on steelmaking of this technical report in 2012 referred to challenges such as optimal division of the steel refining functions, increasing the freedom of choice of main raw materials and environmental harmony. Some solutions have been found so far for most of them, and implemented in actual operation. On the other hand, when we look at the next 20 years, further measures are required to continue reducing the refining costs of high-end and general-purpose steel grades in order to cope with the increasingly tightening business environment. As far as the efficient use of lime stone for desulfurization and dephosphorization is concerned, there is still much room for improving the refining reactions. In addition to the expansion of slag recycling, higher reaction efficiency will be pursued.

In this regard, it is important as written above to utilize various calculation methods that have been developed. Another issue for the future is the effective use of technologies for sensing the phenomena in the reaction vessels, which serve as the basis for calculating the reactions during processing. Moreover, the phosphorus content in hot metal is expected to increase owing to the decline of iron ore quality, and in the current situation where practically all hot metal is pretreated to decrease the contents of undesirable elements, the efficiency of the very pretreatment processes has to be improved as a matter of urgency. Since the use of fluorine was banned, the company has pursued dephosphorization using low-basicity slag. To further improve the efficiency within a short processing time with oxygen blowing, however, it is necessary to quicken slag formation. It is therefore necessary to improve the efficiency of hot metal pretreatment processes focusing mainly on the slag composition and the type of flux best suited to quick slag formation.

## 3. Changes in Continuous Casting Technology

In order to meet the demand for increasingly higher product grades, the technical development of continuous casting has focused on how to incorporate desired high quality in the slabs and blooms of difficult-to-produce steel grades at high efficiency. The technical development activities in this field are explained below. Also presented are the construction and commissioning of the first caster built after the merger, the No. 3 CC of Yawata Works' Tobata Area.

### 3.1 Improvement of continuous casting productivity

The production capacity of a continuous caster is the product of the average casting speed, the cross-sectional size of the slabs/blooms and the casting time. To increase the maximum casting speed, casters were revamped, where necessary, into the vertical-and-bending (VB) type, and the machine length was extended; such measures were completed practically by the end of the 2000s. **Table 2** lists the main specifications of the principal slab casters of Nippon Steel. In addition, to increase the average casting speed making the most of the machine length, measures such as the following were taken: intensive temperature control of molten steel in the ladle; holding the molten steel temperature in the tundish by plasma or induction heating; stabilizing the molten metal level in the mold by preventing unsteady bulging; and stabilizing the heat removal from the mold by reviewing the mold taper. These measures were intended to stabilize the initial solidification of steel, and applied as such throughout the company to realize the synergistic effects of productivity increase and operation stabilization such as decrease of breakouts. **Figure 7** shows the changes in the number of breakouts (BO) of the major continuous casters of the company.

As for individual elementary technologies, typical examples of new developments are given below. Steelmaking operation began to be scheduled using algorithms to which the mathematical optimization technique is applied, and models for optimizing the molten steel temperature have been formulated[46] in relation to the control of the steel temperature in ladles; their field application is expected to expand. Twin-torch plasma heaters of high output are provided for the tundishes of some casters; heat input can be changed by selecting

Table 2 Main specifications of principal slab casters

| | Kashima | | Kimitsu | | | Nagoya | | Wakayama | | Yawata | | Oita | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2CC | 3CC | 2CC | 3CC | 6CC | 1CC | 2CC | 0st | 2st | 2st | 3st | 4CC | 5CC |
| Type | VB | VB | VB | VB | VB | VB | VB | VB | VB | VB | VB | VB | VB |
| Strand | 1 | 2 | 2 | 2 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 2 |
| Machine radius (m) | 9.4 | 10.5 | 9 | 9 | 10 | 7.7 | 9.5 | 11.8 | 11.8 | 7.55 | 7.73 | 7.5 | 7.5 |
| Metallurgical length (m) | 28.3 | 42.7 | 34.3 | 43.0 | 41.2 | 35.8 | 48.4 | 32.6 | 32.6 | 38.7 | 31.7 | 44.5 | 44.5 |
| Start-up | 1974.05 | 1983.06 | 1980.03 | 1982.01 | 2006.11 | 1970.11 | 1980.11 | 2012.07 | 1981.11 | 1979.04 | 1982.12 | 1976.03 | 1976.08 |
| Revamping [VB] | 2000.05 | - | - | - | - | 2000.03 | 1990.09 | - | 1996.04 | 2005.08 | 1991.12 | 1995.07 | 1998.04 |
| Revamping [metallurgical length extension] | - | - | - | 1996.03 | - | 2007.04 | - | - | - | - | - | - | - |
| Tundish shape | Boat | Boat | Boat | Boat | Boat | H-shape | H-shape | Boat | Boat | Boat | Triangle | Boat | Boat |
| Tundish capacity (t) | 32 | 85 | 60 | 60 | 60 | 45 | 60 | 35 | 35 | 30 | 23 | 70 | 70 |
| Casting thickness (mm) | 250, 300 | 250 | 240 (300) | 240 | 240, 300 | 250 | 250 | 250 | 250 | 250 | 250 | 282 | 282 |
| Width range (mm) [twin casting] | 1240–2300 | 700–1625 | 980–2300 | 700–2050 | 980–2300 | 900–2150 | 900–1630 | 1100–1970 [700–1280] | 1100–1970 [900–1280] | 650–1900 | 960–1650 | 1100–2150 | 1100–2150 |

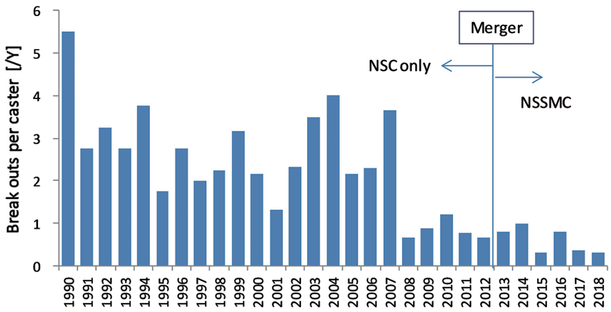


Fig. 7 Change of break out occurrence in main continuous casters

one torch or two torches according to the condition of the steel to cast.[47] The change of metal torches requiring cooling with graphite torches not requiring it was studied, and as a conclusion, hybrid torches composed of a graphite electrode and a metal shaft (to be cooled) in the portion near the tundish cover were finally adopted. They proved effective at increasing the maximum output and improving heating efficiency.[48] The new torches are currently used at Wakayama Works, and expansion of their use to casters of other works is planned.

### 3.2 Responding to demands for higher quality

Increasingly higher properties are required for steel products, and consequently, the production of steel grades that are difficult to manufacture such as high-tensile steels requiring increased addition of alloying elements has increased. It is important in this situation to develop technology to stably incorporate the desired high quality into high-grade slabs/blooms. Such examples are presented below.

#### 3.2.1 Countermeasures against surface defects

Surface defects originating from continuous casting are caused mainly by inclusions caught in the surface layer and surface cracks.

With respect to the defects due to inclusions, to minimize their entering the mold, the tundish size has been increased to facilitate their separation by flotation, and the steel was heated by plasma or induction heating. In addition, the following measures have been taken in relation to the mold and proved effective at enhancing the surface quality: improvement of molten metal level control and mold flux (or powder); prevention of clogging of the pouring system such as the submerged entry nozzles; and electromagnetic stirring in the mold to prevent inclusions from being caught in the solidification shell.[49–51] On the other hand, the molten steel flow in the mold changes greatly depending on conditions such as casting width, casting speed, the diameter of the submerged entry nozzle, the angle of its discharge ports and the power condition of the electromagnetic stirrer. Computer simulation has dramatically advanced over the last few years owing to the improvements of computer capacity and analysis methods, and consequently, the accuracy of electromagnetic flow analysis tools using it has been enhanced. The accuracy of the flow analysis tools has been further improved through comparative studies of past survey results of the surface defects, which became possible after the merger as a synergistic effect. Thanks to the above, accurate prediction of the quality of cast slabs/blooms has been enabled, and casting operation conditions are optimized based on the prediction.

Increasingly higher steel properties began to be required, and the measures against the surface defects caused by cracks are becoming increasingly difficult to implement for the reasons explained below. The temperature range of high-temperature embrittlement expanded owing to factors such as increased alloy addition for higher tensile strength; cracking due to this type of embrittlement is known as the range III embrittlement cracking. On the other hand, hypo-peritectic steel is often selected to realize mutually conflicting properties of high strength, high ductility and high toughness by continuous casting, but this type of steel is prone to longitudinal cracks. Measures have been taken against the range III embrittlement cracking such as optimization of mold oscillation, powder conditions and cooling of slab/bloom corners, as well as slow cooling in the secondary cooling zone by using mist spray.

Besides the above, measures have been taken to enhance toughness by rapid cooling and recuperation in the continuous caster to cause the $\gamma$-$\alpha$-$\gamma$ transformation to obtain a structure of fine grains in the surface layer; this will be explained later in more detail. To suppress longitudinal cracks, mold oscillation and powder conditions have been improved. With regard to the optimization of the powder conditions, in particular, slow cooling in the mold was important, and a high-basicity powder that actively crystallizes cuspidine has been introduced.[52] In addition, a new type of high-viscosity and high-basicity powder has been developed to prevent powder entrapment. The new type powder deposits melilite, a compound containing $Al_2O_3$ and MgO, as a stable crystal phase, in addition to cuspidine; this has proved effective at stabilizing casting operation.[53]

3.2.2 Measures against internal defects

Internal defects of slabs/blooms occur due to causes such as inclusions and Ar gas bubbles trapped inside the casts. In order to prevent blowholes unique to IF steel, all of the company's main continuous slab casters are of the vertical and bending type. In addition, to control the downward steel flow from the submerged entry nozzle, electromagnetic brakes (EMBr, sometimes called the level magnetic fields (LMF)) have been introduced to some casters. The EMBr retards the descending steel flow and accelerates the floatation of inclusions by applying the principle according to which a braking force is created in the direction opposite to the traveling direction of the conductive molten steel by a static magnetic field.

At Nagoya Works, H-shape tundishes are used, each composed of two vessels separated by a tunnel dam. This type of tundish is effective at accelerating the floatation of inclusions, and useful for changing ladles without lowering the steel level in it.[54] The company's continuous casting throughput is increasing, and with the aim of securing the time for the floatation of inclusions in the tundish and preventing the in-tundish steel flow from shortcutting, the steelmaking plants of various works are reviewing the tundish design using computer simulation to enlarge the capacity and optimize the shape.

3.2.3 Measures against center segregation and porosity

To reduce the center segregation of heavy plates and pipes, methods of applying light planar reduction have been developed; such methods include the CC optimum reduction method by divided rolls (CORD) using closely arranged divided rolls and the segregation-free technology (SEFT)[55], whereby light reduction force is applied to the slabs/blooms at the final solidification stage near the tail end of the caster. Such measures against center segregation were put together in the No. 6 CC of Kimitsu Works. They proved effective for quantity production of the plate products requiring strict control of center segregation such as those for UO pipes and offshore structures.[56] For steel grades that require high internal soundness such as ultra-heavy plates more than 100 mm in final thickness, a sufficient reduction ratio (cast thickness/product thickness) cannot be secured at plate rolling, it is difficult to bond center porosity in cast slabs and it is necessary to produce slabs free from center porosity. As an improvement measure, a method called the porosity control of casting slab (PCCS) has been developed, whereby a strong reduction is imposed at the final stage of solidification; this has been applied to the No. 2 CC of Kashima Works commercially and successfully.

The countermeasures against center segregation for bars and wire rods consist of obtaining a solidification structure of equiaxed crystals by electromagnetic stirring and light reduction by disc rolls. For the design of the No. 3 CC in the Tobata Area of Yawata Works, which was constructed after the merger, the expertise in the field of technology was gathered from all over the company. It was commissioned at the end of FY 2018, and the bloom quality is being verified. It is expected to contribute to quantity production of high-grade bars and wire rods.

3.2.4 Oxide metallurgy

Oxide metallurgy[57, 58] has been developed to enhance the product properties by controlling the deoxidation conditions and dispersing fine oxide particles in steel while removing inclusions that cause defects; here, fine oxides are used as the nucleation sites for intragranular $\alpha$ transformation, etc. It is effective, for example, for improving the toughness of the heat affected zones of welded joints, and is widely used for heavy plates for offshore structures. Recently, steel for ultra-high heat input welding use (H-TUFF steel) has been developed, in which oxide particles several tens of nanometers in size are dispersed in steel, and they serve to suppress the growth of crystal grains. These technologies have been shared company wide as a synergistic effect of the merger, greatly increasing the added value of the company's products.

### 3.3 Construction of No. 3 CC at Tobata Area of Yawata Works

Yawata Works has two steelmaking plants in the Tobata and Kokura Areas. To optimize the steel source supplying structure and reduce costs, the iron- and steelmaking processes in the Kokura Area will be closed, and the Tobata Area will be responsible for supplying steel to the downstream processes in the Kokura Area. In this context, a new bloom continuous caster was installed at the Tobata Steelmaking Plant at the end of FY 2018 with the aim of improving the productivity and competitiveness of bars, wire rods and rails. The philosophy of the design for protection against mechanical hazard was applied to the entire caster as the first case in Nippon Steel.[59] On the cast floor, the entire area around the mold, the tundish car and the dummy bar car is surrounded by protective fences with safety doors. In addition, since the equipment moving area is different during the insertion of the dummy bars and during the casting, the work areas are separated variably by double swing doors according to the intrinsic safety design. **Figure 8** outlines the safety measures. In addition, IoT technology including wireless communication systems for detecting operators' positions and movements and equipment operating conditions has been introduced for trial purposes. Its application to other casters is being considered.

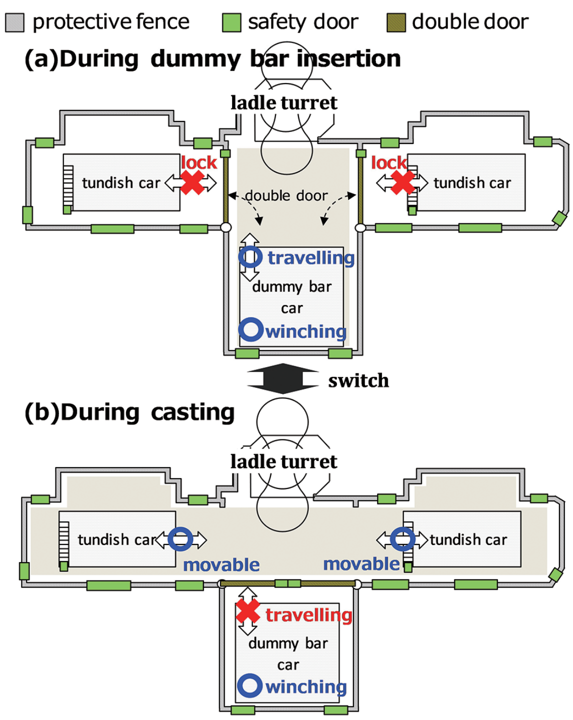



**Fig. 8 Outlines of safety measures**

### 3.4 Future prospects of continuous casting technology

The development of technologies to form the desired high quality in slabs/blooms of difficult-to-manufacture steel grades at high productivity has been presented in this report. Facing increasingly tougher competition in the world market mainly due to the continuous growth of emerging countries as stated earlier, it is important for further business growth to strengthen the technologies that have been fostered. In addition, it is also important to effectively utilize information technology rapidly advancing in the current world. That is to say, data that have been captured simply in the form of images turn, when analyzed, into sensing tools, and it has become possible to combine the large amount of data obtained from the sensing tools with existing sensing data, and analyze them using now inexpensive computers. How should those data be interpreted and utilized? Artificial intelligence may be effective for analyzing them, but rather, valuable findings will be obtained by combining such data with the knowledge and operational know-how that have been accumulated through field activities.

## 4. Conclusion

Over the seven years since the previous special edition on steelmaking was published, emerging steelmakers have grown rapidly, the world market situation has changed and the competition has intensified. Against this background, Nippon Steel has expanded through business integration, and in the field of steelmaking technology, it has enjoyed the synergistic effects of the integration through horizontal diffusion of technology and operational expertise. As the world economy fluctuates significantly, mainly owing to the trade friction between the United States and China, it is necessary to appropriately respond to future market changes. The company will continue slashing through the turbulent environment by further sharpening the technical edges that it has established, utilizing the latest remarkably advancing information technology.

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