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Technical Review

Change and Development of Steelmaking Technology

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1. Introduction

Nippon Steel Corporation has endeavored to secure the world's topmost position in steelmaking technology over the last thirty years, and to this end, pursued technical innovation in the aspects of efficiency enhancement, quality improvement, labor saving and energy conservation in the operation of converters and continuous casting (CC) machines, etc. Different production processes have been selected and used in consideration of the quality level required for different products, and thus, a wide variety of technology has been developed and fostered at the company's different steelworks. In Nippon Steel, what is understood as steelmaking consists of five processes: (i) hot metal pretreatment, (ii) refining in converters, (iii) secondary refining, (iv) continuous casting, and (v) slab/bloom conditioning (see **Fig. 1**). While we believe that the company is presently at the highest level in the world in terms of the elementary technologies in all these processes, new steel producers in developing economies are taking advantage of their modern equipment and low labor costs to threaten our technical advantage. In order to fend off their challenge, in steelmaking as well as in other production processes, Nippon Steel has invested great effort in developing technologies to manufacture products efficiently and cost-effectively that better meet our customers' requirements while providing superior quality to any other steelmakers. The historical development of the steelmaking technology employed at Nippon Steel is outlined in the following pages.

2. Historical Overview of Steelmaking Technology

2.1 Production capacity increase

After domestic steel demand peaked and the economic upheaval following the first oil crisis in the 1970s, the crude steel production capacity of the Japanese steel industry remained broadly stable at 100 to 120 million tons per year. Since commissioning a new steelmaking shop at Yawata Works in 1982, the company has not built any new steelmaking plants. In accordance with the company-wide rationalization plan established in the late 1980s, while iron-and steelmaking plants were closed at some works so as to concentrate production, measures to increase steel production capacity were taken at other works which took over the production share of the partially closed works.

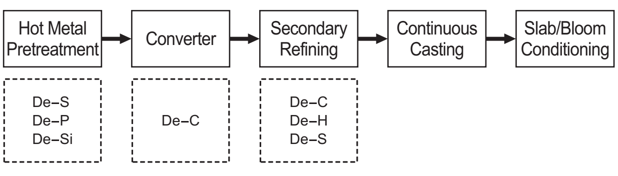

Fig. 1 Steelmaking process flow

In our efforts to increase overall steelmaking capacity, different elementary technologies were developed to increase the processing speeds of various processes so as to shorten the lead time. In tandem with this, measures were taken to increase the production capacities of bottleneck processes in the vertically integrated production flow, as well as to rectify capacity imbalance while repairing furnaces and other periodic plant maintenance shutdowns. As a result, Nippon Steel's total annual crude steel production capacity — including that of its allied companies — has increased to forty million tons.

In the refining process, the heat sizes (ton/charge) of the converters were increased, as were the processing speeds of related processes. As a result, remarkable advances were made in the efficiency of dephosphorization and desulfurization, high-speed oxygen blowing of converters, and high-speed degassing, etc.

In order to increase production of continuous casters, measures to increase the casting speed and width and to produce defect-free slabs/blooms were studied, developed and applied to commercial production at all of the company's steelworks. At the same time, preventative measures to minimize unscheduled production stops due to breakdowns and other problems became part of the daily routine.

The increase in steelmaking capacity at Nippon Steel over the last three decades can be characterized as being not the result of a scrap-and-build approach, nor of constructing new steelmaking shops to replace old ones, but of modifying facilities in existing shops and adding new ones only when necessary.

2.2 Quality improvement

Users demand increasingly higher functionality (lighter weight, better workability, greater strength, etc.) of steel products that are devoid of surface and internal defects as they pursue higher productivity, and as a result, the level of product quality that steelmaking processes must offer has become harder and harder to attain. Nippon Steel has expended great efforts in developing new quality-enhancing technologies to differentiate itself with respect to surface and internal defects, especially for high-grade products. The material used for automotive steel sheets (for outer panels, in particular) has been changed to interstitial-free (IF) steels, as these products came to be manufactured through continuous annealing, but the problem with IF steels is that they are prone to surface defects due to slivers, scabs and blowholes. Various preventive measures were taken against this during continuous casting, leading to the present technology of defect-free slabs. In the field of canning

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materials, on the other hand, to prevent flange cracking and body breakage of thin-gauge sheets during heavy-duty can-forming work in the manufacture of drawing-and-ironing (DI) and laminate cans at can manufacturers, remarkable advances were made in the steelmaking processes to minimize harmful nonmetallic inclusions, render them harmless through hot and cold rolling processes, and evaluate the effects of the inclusions on product quality. Significant advances were made especially in research into measures to break down Al_2O_3 clusters, peculiar to Al-killed steels, during rolling to render them harmless.[1)]

In the meantime, in response to requests for minimum deviation from target chemical composition and steel purification (or less C, P, S, N, H and O content), the operation of the refining processes was tuned for the stable mass-production of steels containing P < 50 ppm, S < 5 ppm, C < 10 ppm and H < 1.5 ppm.

On the other hand, in view of customers' need for use in ever more severe environments, with the application of more efficient working and fabricating methods, etc. to save labor costs and improve manufacturing yields, a wide variety of new products were developed through close cooperation with rolling engineers. Such new products include cryogenic steels, steels resistant to hydrogen-induced cracks (HIC), high-workability steel sheets (soft cold-rolled sheets, corrosion-resistant sheets, bake-hardening (BH) sheets, can sheets free of nonmetallic inclusions, etc.), high-strength steel sheets (high-strength sheets for automotive use, high-burring workability sheets, high-yield-point plates for shipbuilding), high-purity steels for bars and wire-rods (for tire cords and bearings), high-strength rails, and high-performance electrical sheets.

At the same time, quality control technology to maintain product quality at a high level advanced significantly. Quick analysis of alloy elements, analysis of hitherto undetectable microelements, internal quality judgment for slabs (quick evaluation of center segregation, high-frequency ultrasonic tests (HUST)), and on-line defect detection for hot slabs are typical examples of such technologies introduced to the daily routine. The company also created an integrated quality evaluation system by linking information from the steelmaking operation and defect inspections with that from the rolling operation and inspection of final products. This system is being rapidly improved and becoming increasingly sophisticated thanks to the latest advances in information technology.

In order to maintain our technical lead over existing and new steelmakers in Japan and developing countries, it is imperative to continue concentrating our efforts to develop elementary technologies to incorporate the prescribed quality into products at each of the steelmaking steps and for integrated quality control.

2.3 Automation and improved labor efficiency

In our efforts to enhance production efficiency, automation and personnel rationalization were aggressively pursued from the 1980s to the 2000s, and as a result, the number of personnel required for the steelmaking processes decreased, improving productivity remarkably. The number of workers needed to operate principal production facilities per shift are presently as follows, about a third to half those when these efficiencies were first introduced to Japan: 2.5 to 3 per converter; 1 to 2 for each secondary refining facility; and 3.5 to 4 for a two-strand continuous slab caster. We are confident that the level of automation and labor-saving in Japanese steelmaking shops are the best in the world (see **Fig. 2**).[2)]

The Japanese steel industry was the first in the world to introduce process computers to control the blowing operation of converters, and then, remote control was applied to discharging the hot metal from the torpedo ladle cars, and the tilting of converters was automated. Ladle servicing work has also been automated and streamlined by introducing tilting tables to enable all refractory repair work to be performed in one place.

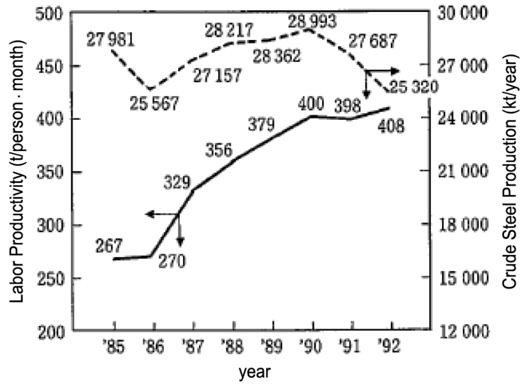


Fig. 2 Change in labor productivity of steelmaking process [2)]

In continuous casting, automatic casting assisted by mold level gauges became common practice, which, together with use of an automatic powder feeder, reduced the workload for casting operations significantly. At the same time, measures were taken for automatic feeding of molten steel from the ladle to the tundish and ladle change operation. As a result, during normal operation, at present casting operators perform the procedures at the start and end of casting and supervise operations during stable casting. There used to be an operators' room for slab cutters at the delivery section of a continuous caster, but now, with the increased reliability of automation systems, cutters are remote-operated mostly from an operator's panel near the molds. Most of these automation measures were implemented by the late 1990s, and thereafter, labor productivity was further enhanced by additional measures.

2.4 Measures for environmental protection and energy saving

In the days when open hearth furnaces were the norm in the steelmaking, plumes of dark smoke from their chimneys were viewed as a symbol of industrial progress, but over the last thirty years, virtually all steelmaking furnaces came to incorporate exhaust gas treatment systems such as the OG system to water-cool and clean the gas from the converters. Since most of our steelworks are in the suburbs of large cities, measures to minimize dust, gas and noise emissions have been meticulously adopted. Computer analysis has been instrumental in studying and selecting the type, capacity and position of dust extractors.

With respect to energy conservation, Nippon Steel expanded the use of energy-efficient continuous casters as a prompt response to the petrol crises in the 1970s through 80s to replace ingot casting. In addition, in the 1980s and thereafter, the company increased the ratio of hot-charged rolling (HCR), and to this end, developed technology to eliminate casting defects and those from hot slab conditioning (hot scarfing and grinding). The hot slab transfer using carrier pallets at Nagoya Works is another example of Nippon Steel's energy-saving activities. At the Muroran Works, the introduction of the "near-net-shaped casting and compact high reduction" (NCR) process proved effective in greatly reducing energy consumption. Further multilateral activities involving production and quality control organizations are required to improve product quality, reduce rejects and excess products, and enhance efficiency.

In consideration for the increased need to save energy and reduce CO_2 emissions, the recovery ratio of LD converter gas (LDG) was increased by finely controlling the equipment in consideration of the increased amount of hot metal pretreatment, and steam recovery boilers were fitted to the dust collecting systems of converters. As a result, some converters recorded a steam generation rate as high as 90 kg/t crude steel. The steam from converter exhaust gas is effectively reused in the steam network of many steelworks.

In consideration of energy and resource saving, our R&D organizations have tackled subjects such as smelting reduction, direct link of the rotary hearth furnace and the scrap melting processes (RHF-SMP, Hirohata Works), electromagnetic casting (EMC), dust recycling, and surface defect-free slab/bloom casting. Of these, the RHF was developed to effectively reuse dust containing Zn, and was applied to commercial production at the Hirohata and Kimitsu Works, contributing to resource saving and a reduction in CO_2 emissions.

Slag from steelmaking processes has been used for roadbeds and other civil construction applications as well as for cement production, but domestic demand for this byproduct has decreased recently. Slag reform to prevent its swelling and discharge of highly alkaline waste water and exploitation of new applications are urgently needed.

3. Changes in Process Technology for Each Steelmaking Stage

3.1 Hot metal pretreatment

Nippon Steel was the first in the world to focus attention on the pretreatment of hot metal with the aim of minimizing P content in steel and reducing production costs through more efficient use of converters for dephosphorization and desulfurization. Accordingly, a multi-stage refining process to reduce the Si, S and P content in hot metal through pretreatment before decarburizing in converters was established and introduced to commercial practice by the 1990s. Here, however, different reaction vessels were used for hot metal pretreatment at different works: (i) torpedo ladle cars at Yawata and Kimitsu; (ii) hot metal ladles at Oita; and (iii) converters at Nagoya. Through comparative studies of these three methods, the converter method (iii) was found most suitable in consideration of the factors and changes in the conditions surrounding steel production such as freeboard effectiveness, flexibility for increased production (possible shortening of processing time, hot metal ratio, and excess heat or thermal allowance), streamlining of intra-works materials handling (torpedo ladle cars, etc.), reduced slag generation, and fluoride-free slag. Eventually, the converter method became mainstream throughout the company.

Aiming for 100% hot metal pretreatment, Nippon Steel now employs the “LD converter-optimized refining process” (LD-ORP, as per item (iii) above) and the “multi-refining converter” (MURC) process for different steels in consideration of their chemical composition. (These two processes will be explained in more detail in Sub-section 3.1.)

1) Desulfurization

Initially, hot metal pretreatment methods were so designed that the same reaction vessel was used for both desulfurization and dephosphorization. However, of the principal impurities in steel, S is the only one that can be removed using reducing reactions, and for this reason and from the viewpoint of total refining efficiency, desulfurization was separated from dephosphorization, which requires oxidizing reactions, as a preliminary step. A desulfurizing method by injecting a CaO-Mg system flux having a strong desulfurizing ability was developed, and besides this, the Kambara reactor (KR) method using a mechanical stirrer offering excellent efficiency was positively reevaluated. Now, Nippon Steel’s steelmaking plants use either of the above two methods of desulfurization based on their specific characteristics.

2) Dephosphorization

The hot metal dephosphorization ratio was increased through construction of new equipment and enhanced processing efficiency (see **Fig. 3**). While the conventional method of hot metal pretreatment in torpedo ladle cars (TPC) enabled stable production of low-P, low-S steels, it decreased the thermal allowance for decarburization in converters, and as a result, imposed heavy restrictions on the scrap ratio. In order to resolve this problem, in consideration of the converters’ large freeboard, high-speed dephosphorization with strong stirring and high scrap melting capacity, the converter-type dephosphorization processes were developed and commercially applied in consideration of the equipment and operational conditions of each works.

Nagoya Works began using the LD-ORP in 1988, becoming the first in the company, utilizing the converters of its former No. 1 Steelmaking Plant, which had only produced steel intermittently.[3] The method consisted of: charging hot metal into a converter designated for the treatment; removing Si and P in the hot metal primarily by using oxygen to take advantage of the large freeboard that torpedo ladle cars cannot offer; removing S by blowing flux from the bottom of the same converter; then after deslagging, transferring the hot metal to another converter; and finally decarburizing under a steady stream of oxygen. Although the process involves the transfer of hot metal to another converter vessel, it uses less CaO, increases the steel yield, and enables stable and high-speed operation of the converters. In appreciation of these advantages, the company planned to apply this process to all steel production. More recently, with the aim of securing improved dephosphorizing efficiency, a new type of LD-ORP, wherein desulfurization is separated from dephosphorization, has been applied commercially to the production of ultra-low-P steels at Nagoya, Kimitsu and Yawata.

Another hot metal pretreatment method using converters that Nippon Steel developed is the MURC process, whereby dephosphorization and decarburization are done continuously in one converter vessel with intermediate deslagging between them.[4] This process enables efficient dephosphorization using low-basicity slag and under high oxygen potential, making good use of the strong stirring and high-speed oxygen blowing functions of converters. Using this process, the slag formed during decarburization is left in the vessel and reused for the dephosphorization of the following charge, which enables counter-flow refining with minimum heat loss and far less slag generation. However, since hot metal pretreatment and decarburization are done continuously using the same converter

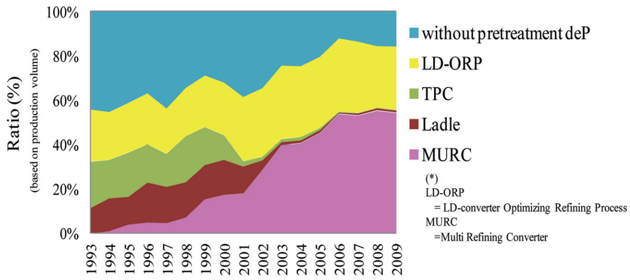
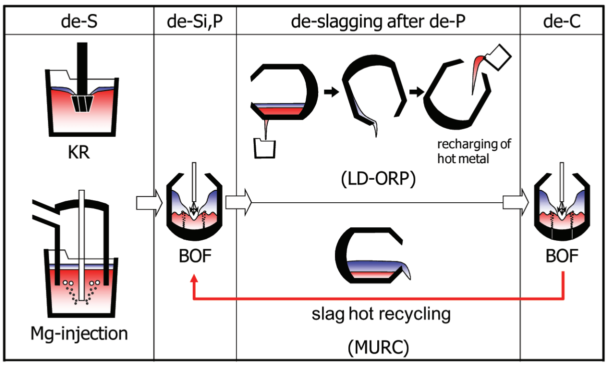


Fig. 3 Change in hot metal dephosphorization ratio



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

Fig. 4 Principal processes of primary refining in Nippon Steel

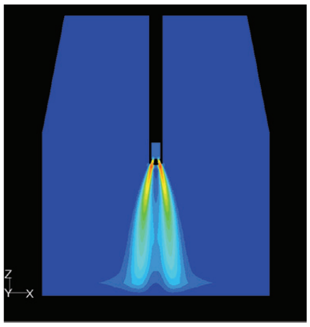


Fig. 5 Computer simulation example of top-blown oxygen jets

vessel, the processing time tends to be longer, and for this reason, it was necessary to shorten the processing time to expand the application of this process to mass-production of steel. Through improvement activities, the processing time, which was initially about fifty minutes, has been shortened to 35 to 37 minutes. This process has proved effective in the production of ordinary steels (except for ultra-low-P steels) in terms of decreased CaO consumption and slag generation and effective use of the thermal allowance, and for this reason, after being developed at Muroran, it was later introduced commercially at Oita, Kimitsu and Yawata.

Fig. 4 shows the principal processes of primary refining (hot metal pretreatment and converter refining) commercially practiced at Nippon Steel. As explained above, hot metal pretreatment methods that make good use of the advantages of converters have expanded rapidly since the 1990s, and as a result, as seen in Fig. 3, the LD-ORP and MURC processes have increased in share by replacing the pretreatment methods using torpedo ladle cars or hot metal ladles. Nippon Steel plans to increase the ratio of hot metal pretreatment to 100% by 2013, and by so doing, further improve the steel refining efficiency.

3) Desiliconization

Any increase in Si content in hot metal leads to increased CaO consumption in steelmaking, causing increased cost and slag generation. As the technology for stable operation of large blast furnaces permeated and Si content in the hot metal remained stably low, some of the company's steelworks began to aim for a moderate Si content level through optimum hot metal pretreatment by applying desiliconization only when the Si content of the hot metal became too high (top-cut desiliconization). This process is expected to expand to other works to decrease steelmaking slag and improve molten steel yield.

3.2 Converter refining

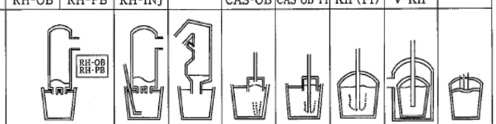
With the increase in the hot metal pretreatment ratio, the role of converters came to center on decarburization, while in the meantime, various methods of rapid refining were developed to enhance productivity. The oxygen blowing rate was raised, and this, together with slopping sensors and exhaust gas analyzers, shortened the decarburizing time in converters down to as little as nine minutes. With high-speed oxygen blowing, the lance design and blowing patterns (blowing rate, lance height, etc.) became increasingly important. Actually, the molten steel yield decreases with increased oxygen blowing speed, and suppressing dust generation is an important countermeasure to the yield decreasing. In consideration for this, a new lance tip design was developed to control the oxygen jet speed making use of the expansion characteristics of the supersonic jet (see **Fig. 5**). The latest developments in numerical calculation technology were instrumental in the lance-tip design: this enabled the combined behavior of jets from a multi-nozzle lance tip, which significantly affects the blowing characteristics, to be accurately predicted.

3.3 Secondary refining

1) Ruhrstahl-Heraus (RH) degasser and "revolutionary degassing activator" (REDA)

Nippon Steel has long applied dehydrogenization to molten steel for plates using degassers. In addition, the production of steels that require decarburization such as IF steels increased rapidly as continuous annealing of cold-rolled sheets for automotive use increased. All these, together with the increase in the width of automotive sheets (increased casting width) and higher casting speed of continuous casters, made it necessary to shorten the processing time for secondary refining. In response, technical improvements advanced to accelerate the decarburizing reactions.[5] Among the various methods of secondary refining, the RH and REDA processes survived in Nippon Steel as mainstays owing to their high processing speed. So as to shorten the processing time, elementary techniques were developed such as an increase in the snorkel diameters, that of the circulating gas volume, and a capacity increase in the evacuating system (see **Table 1**). One example is the preliminary vacuum technique whereby air is evacuated from the whole degassing system except the reaction chamber beforehand to shorten the time to reach the desired degree of vacuum at the start of processing. New RH degassers featuring newly designed evacuating systems with a

Table 1 Refining functions of secondary refining equipment in Nippon Steel[4]

		RH			DH	CAS		KIP		LF
		RH-OB	RH-PB	RH-INJ		CAS-OB	CAS-OB-PI	KIP(PI)	V-KIP	
Equipment Outline										
Functions	Deoxidation	○	○	○	○	○	○		○	○
	Decarburization	○	○	○	○				○	
	Dehydrogenization	○	○	○	○				○	
	Desulfurization		○	○			○	○	○	○
	Heating	○	○	○		○	○			○
	Composition Adjustment	○	○	○	○	○	○	○	○	○
	Clean Steel	○	○	○	○	○	○	○	○	○

combination of a high-performance booster, an ejector and a high-capacity mechanical pump, were installed at Nagoya (No. 3 RH) and Kimitsu (No. 3 RH), which proved effective in accelerating both the decarburization and dehydrogenization treatments.[6)]

Besides the above, multi-functional burners (MFB), RH-OB, and RH-Injection are installed to heat the steel during processing by oxygen blowing, preventing the vacuum vessel from cooling and injecting powder for desulfurization.

2) "Composition adjustment by sealed argon bubbling" (CAS) and "Kimitsu injection process" (KIP)

These simplified secondary refining processes were developed to replace conventional methods of deoxidation and composition adjustment using ladle bubbling after tapping from converters, and are now widely applied to steels not requiring the vacuum degassing treatment.

3) Ladle furnace (LF)

In order to shorten the processing time for secondary refining, Nippon Steel does not use LFs for ordinary steels, but uses them for steels of very low oxygen content, as well as those requiring additional heating such as some high-carbon steels and those for bars, wire-rods and special steel plates. Because of the characteristic product mix, the Steelmaking Plant at Muroran Works basically uses LF for all its steel production.

3.4 Continuous casting

Nippon Steel has developed various advanced casting technologies to meet product requirements, and applied them commercially to continuous casters for high productivity of high-quality slabs/blooms.[7)] The company operates large capacity continuous casters of the type that does not involve any bending prior to completion of solidification at high casting speeds in many steelworks across Japan; they incorporate measures against steel contamination, nonmetallic inclusions, surface defects (nonmetallic inclusions and cracks), and center segregation. Of these, Nos. 4 and 5 CCs at Oita and No. 2 CC at Nagoya have a capacity for 400,000 tons/month each, and No. 6 CC of Kimitsu is capable of producing slabs of high-grade steels for plate. With these advanced facilities, Nippon Steel currently stands at the highest level of CC operation in the world in terms of product quality and efficiency.

1) Productivity improvement

The production capacity of a continuous caster is the multiplication product of average casting speed, sectional area of casting and net operating time. Nippon Steel has focused attention on increasing maximum casting speed, and to this end, revamped casters into vertical-and-bending type machines and extended their effective length. At the same time, the company actively took measures to stabilize the solidification process through measures to make the most of extended machine length and increased casting speed: such measures include fine control of steel temperature in the ladle; stabilizing the casting temperature using plasma or induction heating in the tundish; stabilizing the steel-surface level in the mold by preventing non-steady bulging; and stabilizing heat transfer in the mold by optimizing the mold taper.

Measures against surface and internal defects (to be explained below) were applied to those steels for which the maximum casting speed was restricted for quality reasons. In addition, measures were taken to allocate different steels to different casters in consideration of production lot formation.

Further, to enhance the level of operational practice, measures were taken to minimize non-scheduled machine stops such as breakdowns and segment failures to bring about remarkable improvement. All these efforts together resulted in a significant increase in the productivity of casters.

2) Countermeasures against surface defects

The principal causes of surface defects in continuously cast slabs/blooms are nonmetallic inclusions caught in the surface layers and cracking.

Widely varied technology has been developed and tried over a long period to suppress these causes. Through these efforts, it became clear that the steel flow in the mold had significant influence over nonmetallic inclusions in the surface layers, and based on this finding, comprehensive operational control around the mold by means such as electromagnetic stirrers (EMS),[8)] intensive control of mold bath level, improvements in powder technology, and prevention of clogging in the feeding routes such as submerged entry nozzles, was found to be very important (see **Fig. 6**).

Regarding the control of in-mold steel flow, numerical simulations were applied to the flow analysis using a simulation software package, Fluent, and based on the results, nozzles were designed and EMS and other flow control devices were developed and provided around the molds of the principal casters.

Furthermore, applying sophisticated methods of electromagnetic field analysis and fluid analysis, a new electromagnetic tool,[9)] which was used to minimize both nonmetallic inclusions and cracks in the surface layers, was developed and commercially applied to the principal casters (see **Fig. 7**). Besides this, the development of electromagnetic casting (EMC)[10)] was also promoted.

3) Countermeasures against internal defects

Internal defects in slabs/blooms result from such undesirable issues as nonmetallic inclusions and argon bubbles caught by the

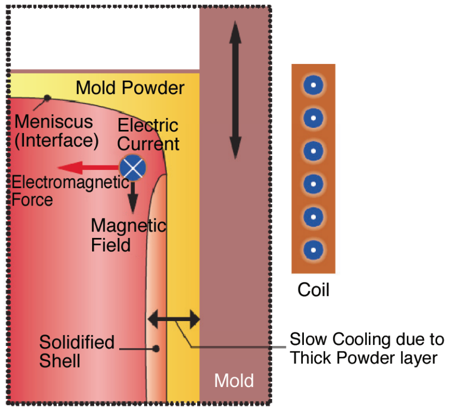


Fig. 6 Conceptual diagram of electromagnetic casting (adapted from Nippon Steel Monthly, Aug.&Sep. 2004)

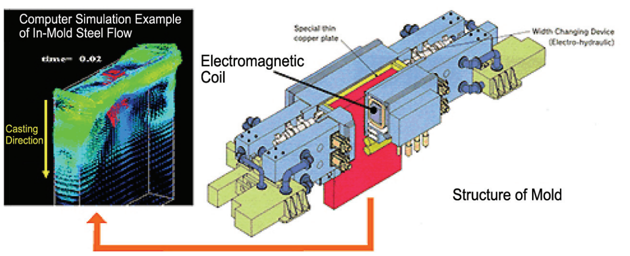


Fig. 7 Devices around mold and computer simulation example of in-mold flow

steel flow and brought inside, as well as shrinkage cavities.

In order to prevent blowholes peculiar to IF steels, all principal slab casters of the company whose casting speeds exceeded 1.3 m/minute were modified into vertical-and-bending type machines. For example, while Kimitsu Nos. 2 and 3 CCs were built after the vertical-and-bending design, the upper parts of the curved-mold casters at Nagoya, Oita, and Yawata were revamped into vertical-and-bending designs in preparation for the production of IF steels. In addition, some works introduced electromagnetic brakes to decelerate the downward steel flow in the mold, which proved effective in helping nonmetallic inclusions rise to the steel surface as well as reducing the length of the mixed steel portion during sequential casting of different steel grades.

The No. 2 CC at Nagoya, shown in **Fig. 8**, has an H-shaped tundish, which proved effective in accelerating the surfacing of nonmetallic inclusions in the tundish and thus preventing inclusion problems upon changing of the ladle.[11]

Besides the above, in accordance with the company-wide efforts to increase the continuous casting production, the steelworks are reviewing their tundish designs using computer simulations to prevent steel from taking the shortest route so as to secure enough time for nonmetallic inclusions to surface in tundish, and based on these results, the capacity of the tundishes is being increased and their shape optimized.

4) Countermeasures against center segregation

As countermeasures to prevent center segregation of plates and sheets for pipe forming, light reduction is applied to the cast slabs at the final stage of solidification. For example, in the case of the “CC optimum reduction process by divided rolls” (CORD) and the like, segment rolls closely aligned and divided into sections along the shaft are used; and in the case of “segregation-free technology” (SEFT) and similar, light planar reduction using mechanical presses is employed.[12] Through the development of these technologies, they were put to commercial use in Kimitsu No. 6 CC, and the caster now plays an important role in the mass-production of slabs for UO pipes and marine structures, for which center segregation is controlled strictly. The measures against center segregation of wire-rods consist of using electromagnetic stirrers to form an equiaxed solidification structure and light reduction using disc rolls.

5) Oxide metallurgy

Nippon Steel developed oxide metallurgy to make use of fine nonmetallic particles while eliminating harmful nonmetallic inclusions.[13] Although we cannot explain it herein in more detail due to space limitations, the developed technology was commercially applied recently to disperse oxide and sulfide particles tens of nanometers in size to enhance the value of the products.[14]

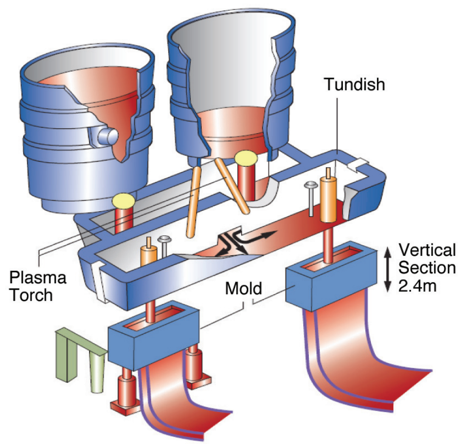


Fig. 8 Equipment of Nagoya No.2 CC (adapted from Nippon Steel Monthly, Jul. 2004)

3.5 Ingot casting

At Nippon Steel, ingot casting only survived until recently at Nagoya Works for the production of such special plate products as large-unit-weight plates and those designated for forging, but this was discontinued as of March 2008 and replaced by continuous casting. As a result, the continuous casting ratio at the company is now 100%.

3.6 Slab/bloom conditioning

The surfaces of slabs/blooms from continuous casters are conditioned mostly through all-face scarfing by machine scarfers in combination with partial conditioning, either manual or mechanical; hot grinders are used at some works for hot charge rolling. The conditioning ratio is increasing with increased production of IF steels and high-grade steels prone to cracking. In order to prevent surface cracks, it is essential to improve the initial solidification conditions in the mold (optimization of mold oscillation and use of powder) and improve the functions of the secondary cooling sections of casting machines.

4. Closing

Outlines of the historical development of Nippon Steel’s steelmaking technology over the last three decades have been presented above. In view of the increasingly tough cost competitiveness from developing countries and based on the accumulated technology to meet customer requirements, the steelmaking division will continue making their utmost efforts to supply high-quality slabs/blooms economically to downstream processes.

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