Abridged version

KAWASAKI STEEL TECHNICAL REPORT

No.37 (October 1997)

Rolling Technology and Modernization of Chiba Works

Construction of New Stainless Steelmaking Shop with Highly Flexible Raw Material Choice:Construction and Operationof No. 4 Steelmaking Shop at Chiba Works

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Synopsis :

Kawasaki Steel started materialization of modernization project of the Chiba Works to establish environmental-friendly iron and steel works directing toward the 21st century. This project includes construction of No. 4 steelmaking shop and No. 3 hot strip mill, and reorganization of the east area of the works. No. 4 steelmaking shop, located at the west area of the works, was designed to produce especially stainless steel and high carbon steel and to replace the old No. 1 steelmaking shop. In the steelmaking process, an introduction of smelting reduction-decarburization process realizes a wide range of raw material choice. To meet the demand for a clean ultra low carbon stainless steel, VOD and vertical-bending type continuous caster were adopted. The operation of this new steelmaking shop started in July 1994 and has successfully contributed to the improvement of productivity, product quality and reduction in costs.

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Construction of New Stainless Steelmaking Shop with Highly Flexible Raw Material Choice: Construction and Operation of No. 4 Steelmaking Shop at Chiba Works*



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1 Introduction

At Chiba Works, new steelmaking and hot rolling facilities were constructed as part of a modernization plan aimed at creating an environmental-friendly iron and steel works. In the steelmaking department, as a replacement for No. 1 steelmaking shop which had been in operation for 40 years and was reaching its limits in terms of both capacity and quality, a new shop (No. 4 steelmaking shop) exclusively for specialty steels, centering on stainless steel, was constructed in West Plant of Chiba Works, where the site's key facilities, No. 6 blast furnace and No. 3 steelmaking shop, were already located.

No. 4 steelmaking shop was completed in a period of 27 months after the start of pile driving in April 1992, and was started up in July 1994.

Figure 1 shows the trend in stainless steel production and in the ratio of production by the smelting reduction method. After startup, output was increased smoothly while confirming equipment functions and the reliability of the quality of the slabs which are the product of this

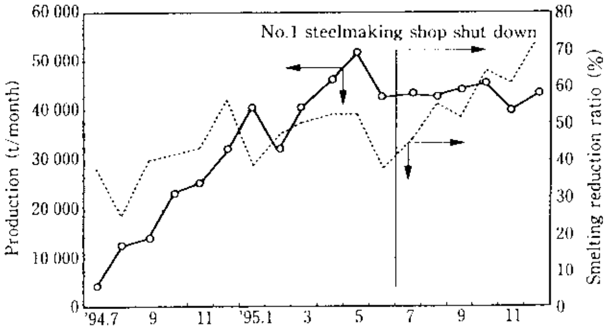


Fig. 1 Trend of stainless steel production and smelting reduction ratio in No. 4 steelmaking shop

* Originally published in *Kawasaki Steel Giho*, **28**(1996)2, 206–212

plant, and a 100% transfer of production from the No. 1 steelmaking shop was completed in approximately one year. The ratio of production by direct smelting reduction of Cr ore also exceeds 70%, achieving flexibility in the choice of raw materials in response to market-related changes in the price of Cr raw materials.

This report describes the concept of the construction of No. 4 steelmaking shop, the outline of the technology and equipment for implementing that concept, and the results of operation.[1-3]

2 Basic Concept and Process Design of No. 4 Steelmaking Shop

The basic concept of No. 4 steelmaking shop and the concept of the process and equipment are shown in **Fig. 2**. The aim was to construct a plant and process which would eliminate the problems and limits of the existing No. 1 steelmaking shop and serve in the 21st century as a steelmaking shop which supports a state-of-the-art steel works specializing in sheet products.

2.1 Production Process

In deciding the production process, which governs the cost and quality of products, special attention was paid to creating a process with flexibility in the slection of Cr, Ni, and other main raw materials, which account for the major portion of the cost of producing stainless steel, and to the combination of a high-function secondary refining process and continuous caster. To reduce the use of high-carbon FeCr alloy, as an electric power intensive product, the new shop takes advantage of its location in an integrated steel works, which makes it possible to use low-cost oxygen and coke and also to utilize converter exhaust gas effectively. The smelting reduction process for Cr ore utilizing coal energy was therefore adopted. For increased raw material flexibility, full consideration was also given to the use of stainless scrap in large quantity. To meet increasing demand for ultra-low carbon, ultra-low nitrogen stainless steel, the vacuum decarburization process (VOD) was adopted in the secondary refining equipment, responding to stricter quality requirements, and a vertical-bending type continuous caster was introduced to solve the problem of pencil defects in slabs.

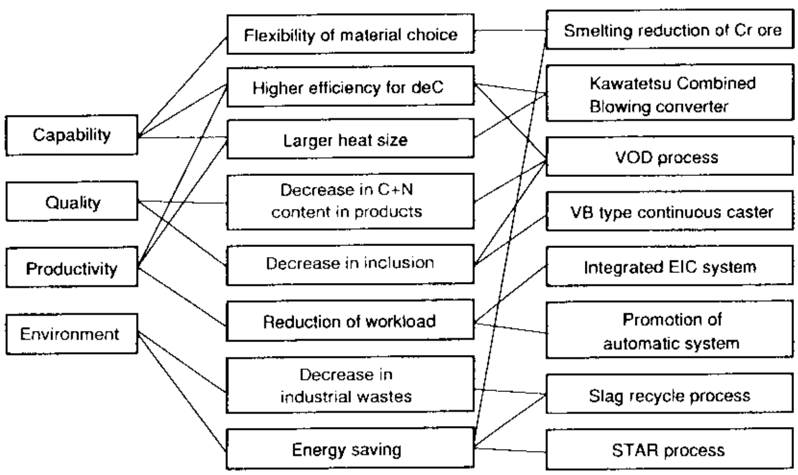
Figure 3 shows an outline of the stainless steelmaking process which was selected based on this fundamental concept. The figure also shows the features of each process and the composition and temperature trend of the molten metal.

2.2 Labor Productivity

As one method of improving labor productivity, the production capacity was strengthening by adopting a large heat size and other basic plant design features. Efforts were also made to realize common use of equipment and personnel by laying out the new equipment adjacent to the existing No. 3 steelmaking shop and No. 3 continuous caster shop. The unifying operation rooms have been realized by adopting automation and remote operation to the newly introduced equipment. The adjacent location of No. 3 and No. 4 steelmaking shops has also been effective in creating a flexible production system with multiple molten steel supply routes to the continuous casters.

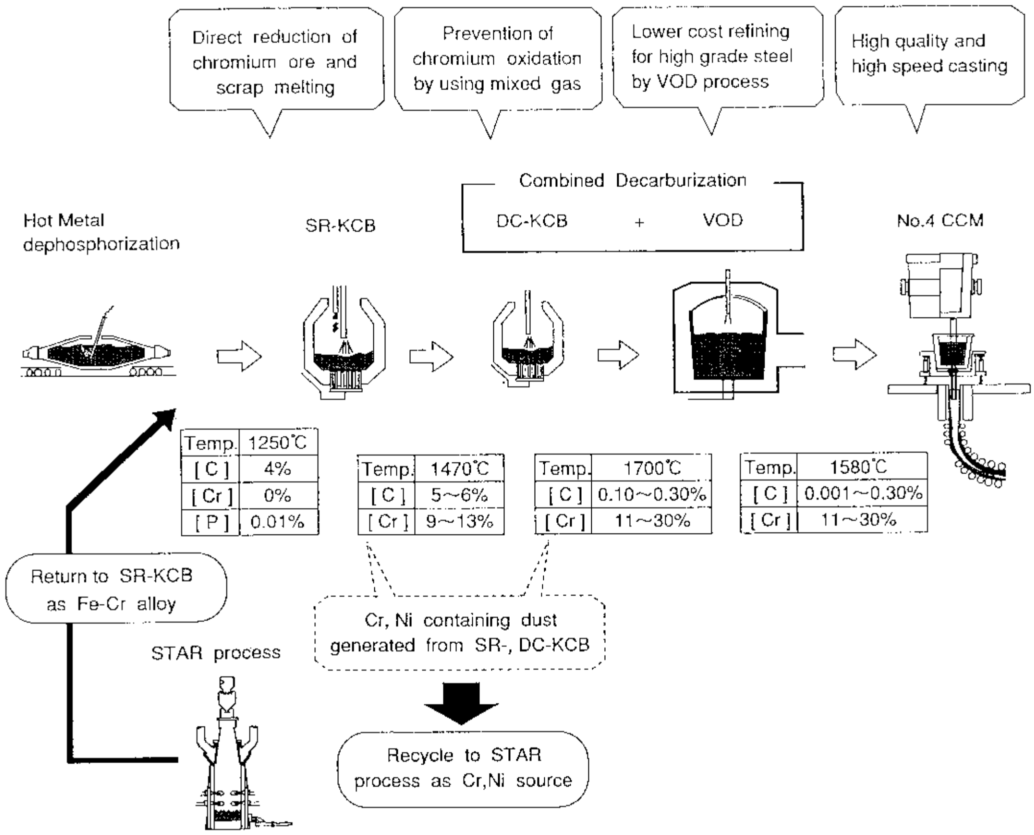
2.3 Environmental Protection

Environmental protection is an important requirement for an environmental-friendly iron and steel works. From this viewpoint, one aim was to establish a complete recycling system for the dust and slag produced in the steelmaking shop. A STAR furnace, which reduces



deC : decarburization VB : Vertical-Bending
EIC : Electric, Instrumention, process Computer

Fig. 2 Basic design concept of new steelmaking shop



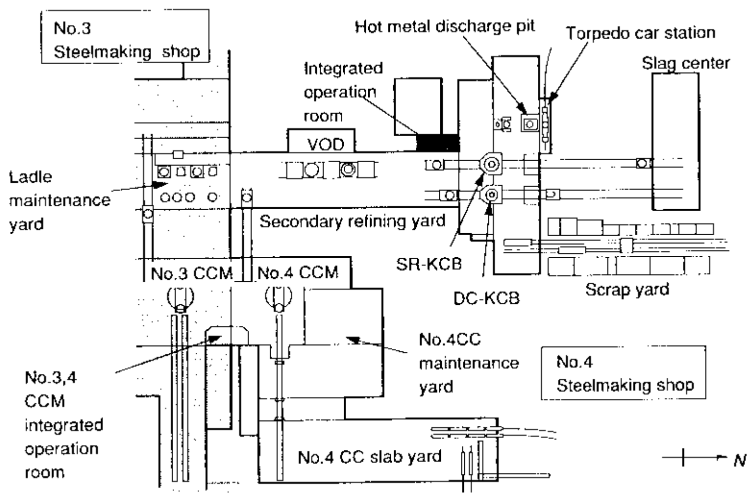


Fig. 4 Schematic view of No. 4 steelmaking shop

and recovers the valuable metals Cr and Ni contained in dust was constructed[4] as part of this project, as part of a process in which these materials can be recycled by the smelting reduction furnace as metals. Slag is recycled as flux by the STAR furnace and other processes in the ironmaking department, and is also processed into a commercial product as road construction material.

3 Layout of No. 4 Steelmaking Shop

The layout of No. 4 steelmaking shop and No. 4 continuous caster shop is shown in **Fig 4**. The secondary refining yard in No. 4 steelmaking shop is laid out in an extension to the north of the ladle maintenance yard of

No. 3 steelmaking shop, which produces mainly carbon steel. A converter shop and raw material yard are laid out further to the north, at the right angles to the secondary refining yard. This layout allows common use of the ladle handling crane and ladle maintenance equipment and personnel,and made it possible to secure external access routes to both steelmaking shops. Construction of a refractory center for dismantling and relining charging ladles, ladles, and tundishes adjacent to No. 3 steelmaking shop has also rationalized refractory maintenance.[5]

In the raw material yard, a station for receiving torpedo cars which have completed the hot metal pretreatment process was constructed in parallel with a scrap yard capable of stocking multiple grades of stainless scrap in a layout which enables efficient raw material supply. The slag center is located adjacent to the converter and raw material yard, which minimizes the transportation of high-temperature molten material in the works by allowing prompt cooling and solidification of slag after tapping at the converter.

No. 4 continuous casting shop is laid out in parallel with the existing No. 3 continuous casting shop with the same casting floor, aiming at unification of the operation rooms and pooling of personnel to respond to non-steady operation. At the same time, remote monitoring and automated control of torch cutting and slab transportation have also been realized. At the adjacent No. 3CC and No. 4CC slab yards, slab handling control is performed by automatic cranes, enabling directly linked operation with No. 3 hot rolling mill.

4 Outline of Equipment and Results of Operation of Respective Processes

4.1 Cr Ore Smelting Reduction Process

4.1.1 Smelting reduction converter (SR-KCB)

Table 1 shows the main specifications of the smelting reduction converter. The furnace is a strongly-stirred combined-blowing type converter with a removable bottom equipped with eight duplicated tuyeres for bottom blowing pure oxygen, and has a sufficient inner volume to handle the large amount of slag which is formed during smelting reduction refining. The top blowing lance and blowing system also have a larger capacity than ordinary converters in order to secure the necessary capacity for the smelting reduction of raw Cr ore. To enable direct charging of Cr ore sand into the converter, a water-cooled Cr ore lance, which is inserted into the converter, was developed.

Table 1 Specifications of SR-KCB

Facilities	Items	Specifications
Vessel	Type	Strongly stirred-type combined blowing converter
	Heat size	Ave. 178.0 t/ch
	Capacity	Height 9 105 mm Diameter 8 260 mm Volume 372 m³
Top blowing	Type	Water cooled lance
	O_2 flow rate	Max. 950 Nm³/min
Bottom blowing	Tuyer type	Duplicated tube × 8
	Gas species	Inner : O_2, N_2, Ar Annulus : Propane, N_2, Ar
	Gas flow rate	0.5~1.2 Nm³/min · t
OG system	Suction capacity	Max. 165 000 Nm³/h
	Dust collector	Saturater + RSW (Cooling water 750 m³/h)
	Boiler system	Lower, upper boiler and 1~4 th contact boiler
	Induction fan	2 by series(P = 2 650 MPa)
Cr ore lance	Type	Water cooled lance with inner lining by ceramic

In the exhaust gas treatment system, membrane-type water-tube boiler OG equipment was adopted at the hood top, and a contact-boiler was installed in the flue of the top boiler, raising the efficiency of sensible heat energy recovery from exhaust gas.

4.1.2 Results of smelting reduction operation[6,7]

Table 2 shows a comparison of a typical Cr ore used at No. 4 steelmaking shop and the pre-reduced Cr pellets which were used at No. 1 steelmaking shop. At No. 1 steelmaking shop, 60–70% pre-reduction was performed to produce pre-reduced pellets. However, Cr ore is used without pre-reduction at No. 4 steelmaking shop, which places special requirements on the converter.

Table 2 Comparison of typical chemical composition between pre-reduced Cr pellet and Cr ore (%)

	Cr_2O_3	Metallic Cr	Fe_2O_3	FeO	Metallic Fe	Al_2O_3	MgO	SiO_2	CaO
Pre-reduced Cr pellet in No.1 steelmaking shop	18	20	tr	1	20	17	11	5	1
Cr ore in No.4 steelmaking shop	45	tr	6	20	tr	15	10	2	tr

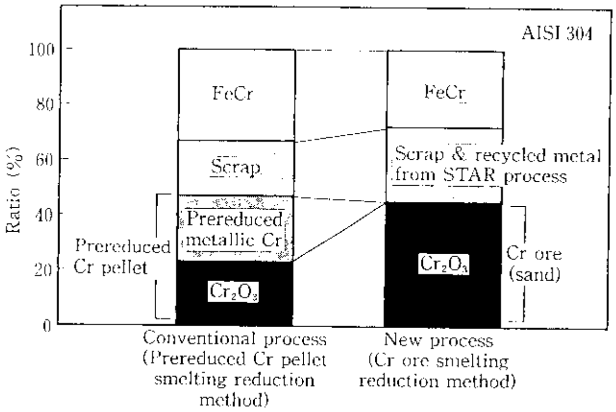


Fig. 5 Comparison of Cr balance between two processes

Specifically, because oxides of Fe and Cr exist in unreduced form, a large amount of heat compensation is required for the endothermic reaction, and because the reducibility of the material is inferior, rapid melting of the oxides including gangue is necessary. Regarding the grain size, the larger part of the ore, particularly from South Africa, is fine-grained sand, and it was therefore necessary to develop a scatter-free method of direct addition to the converter.

At No. 4 steelmaking shop, it was possible to obtain a Cr ore addition yield of 98% or higher by adopting an in-furnace addition method for Cr ore sand using a special lance. This method was adopted based on experiments with the actual equipment at No. 1 steelmaking shop and a computer analysis of the in-furnace gas flow pattern. Where reduction behavior was concerned, the Cr yield from Cr ore was maintained at 90%, and the Cr_2O_3 concentration of the slag was held to 1.0% or under, even at a Cr ore addition rate of 5.5–6.5 kg/min·t, which is 2.5–3.0 times greater than with the pre-reduced Cr pellet method formerly employed at No. 1 steelmaking shop in terms of Cr_2O_3 addition rate. These improvements were obtained by optimizing the heat compensation in large-volume top oxygen blowing, the molten metal temperature, and the slag composition.

As a result, it has become possible to substitute Cr ore and stainless scrap for more than 70% of the Cr source for stainless steel. **Figure 5** shows an example of the breakdown of Cr sources in an austenitic stainless steel (AISI 304) in comparison with the conventional process using pre-reduced Cr pellets. The amount of Cr recovered by reduction from unreduced Cr_2O_3 has increased, and including the effect of an increase in the consumption of scrap, it has become possible to reduce the consumption of FeCr.

4.2 Combined Decarburization Process

4.2.1 Decarburizing converter (DC-KCB)

As the decarburizing furnace (**Table 3**), a strongly-stirred, pure oxygen combined-blowing converter capable of blowing dilute gas was adopted for primary decarburization of the crude hot metal tapped from the smelting reduction converter at [Cr] = 9–13%. In the converter decarburization proceeds to [C] = 0.10–0.30%, which is the most appropriate concentration for combined decarburization with VOD while suppressing the oxidation of Cr. The converter is the same type as in the smelting reduction converter. The removable bottom is also a common type in consideration of the shared use of exchange equipment and spares. However, the vessel dimensions and the specifications of the gas supply equipment, exhaust gas treatment equipment, and other parts are not identical because of the large differences between smelting reduction refining and decarburization refining of stainless steel. These features were optimized for the amounts of gas and slag produced during blowing. The electrical and instrumental system makes it possible to control the oxygen flow rate, oxygen dilution ratio, and the exhaust gas suction in response to the decrease in decarburization efficiency as decarburization proceeds.

Table 3 Specifications of DC-KCB

Facilities	Items	Specifications
Vessel	Type	Strongly stirred-type combined blowing converter
	Heat size	Ave. 178.0 t/ch
	Capacity	Height 8 905 mm Diameter 6 740 mm Volume 242 m^3
Top blowing	Type	Water cooled lance
	O_2 flow rate	Max. 400 Nm^3/min
Bottom blowing	Tuyer type	Duplicated tube × 8
	Gas species	Inner : O_2, N_2, Ar Annulus : Propane, N_2, Ar
	Gas flow rate	0.5~1.2 $Nm^3/min \cdot t$
OG system	Suction capacity	Max. 90 000 Nm^3/h
	Dust collector	Saturater – RSW (Cooling water 390 m^3/h)
	Boiler system	Lower, upper boiler and 1~4 th contact boiler
	Induction fan	2 by series (P = 2 650 MPa)
Slag stopper	Type	Pneumatic
	Detector	EMLI-type slag detector

4.2.2 Secondary refining equipment (VOD)

As the decarburization process for stainless steel, combined decarburization was adopted to achieve high productivity with the converter and to take advantage of the superiority of vacuum decarburization as a secondary refining process to reduce Cr oxidation and decrease Ar consumption. As secondary refining equipment, the VOD was introduced to respond to the increasing demand for ultra-low carbon, ultra-low nitrogen stainless steel predicted in the future.

Figure 6 and **Table 4** show a schematic view and the main specifications of the VOD equipment.

The VOD process comprises two vacuum treatment tanks and two ladle treatment cars in one vacuum exhaust system, considering the productivity of ultra-low carbon stainless steel, which requires a long vacuum decarburization time. This arrangement makes it possible to shorten the vacuum treatment interval and perform overlapping vacuum and final alloy addition treatment. Moreover, because it must be possible to achieve ultra-low carbon and ultra-low nitrogen contens in the high Cr region of ferritic stainless steels, a vacuum unit with a large suction capacity and bottom blowing gas equipment with a high flow rate were adopted.

As the exhaust gas treatment equipment, dry-type dust-collecting equipment using gas coolers and bag filters was adopted, preventing deterioration of the exhaust capacity due to dust adhering to the boosters and lightening the load on water treatment equipment.

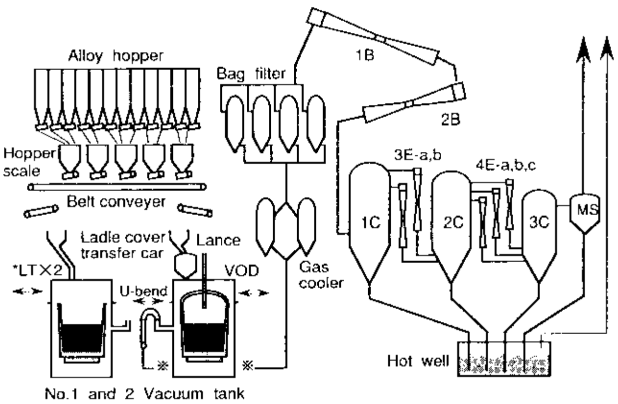


Fig 6 Schematic view of VOD equipment

Table 4 Specifications of VOD

Item	Specification
Type	Twin tank and single vacuum unit
Ladle cover transfer car	3 for 1 VOD cover and 2 LT covers
Heat size	178 t
Vacuum unit	2 boosters and 2 step - 5 ejectors
Suction capacity	6 800 kg/h at 186 hPa 700 kg/h at 0.7 hPa
Vacuum attainable	0.3 hPa
Dedusting system	Dry type
O_2 lance	Multi holes water-cooled type
O_2 blowing	Max. 60 Nm^3/min
Agitation gas	50 ~ 3 600 Nl/min (Ar and/or N_2)
Freeboard of ladle	1 530 mm (at 178 t/ch, new lining)
Number of alloy hopper	20

4.2.3 Results of combined decarburization operation

In the combined decarburization process, improvements were made to optimize the total process while taking full advantage of the respective features of the converter and VOD. Specifically, the technique of decarburization in wide range of carbon content without increasing Cr oxidation was developped by making the maximum use of the advantages of Kawasaki Steel's strongly-stirred oxygen combined-blowing converter.[8]

Figure 7 shows the relationship between tapping [C] (= [C] before VOD treatment), which was decided considering both productivity and the decarburization refining cost, and the target [Cr] and [N]. At No. 4 steelmaking shop, it was possible to realize efficiently a reduction in [C] before VOD treatment without increasing Cr oxidation by using techniques for decreasing Cr oxidation at the converter. The reduced decarburization load on the VOD achieved in this manner also has the effect of reducing the total oxygen concentration of the steel after VOD treatment. In combination with the optimization of other deoxidation treatments, this has contributed to the stable achievement of [O] < 60 ppm even with Si-killed AISI 304, and thus to an improvement in the quality of cold-rolled steel sheets.[9]

4.2.4 High-efficiency production of ultra-low carbon stainless steel

Figure 8 shows the results of VOD decarburization treatment of 18% Cr and 30% Cr super ferritic stainless steels with the new VOD. Bottom-blowing stirring using a high-flow rate slit plug and control to a high degree of vacuum during decarburization treatment have made it possible to treat large heat sizes at a decarburization

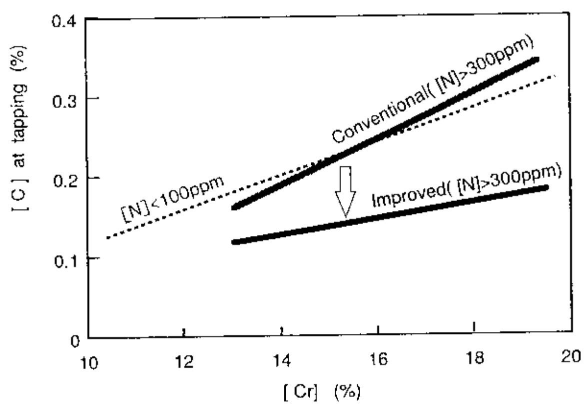


Fig. 7 Relation between optimum carbon content at tapping and chromium, nitrogen content level in combined decarburization process

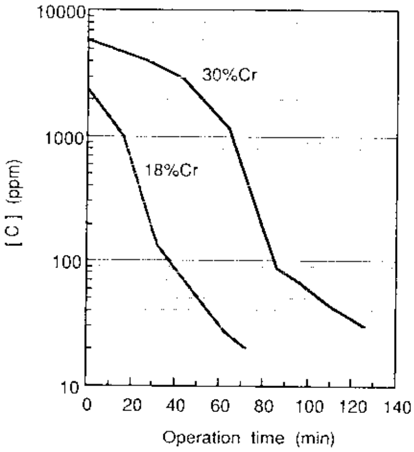


Fig. 8 Result of VOD operation for super ferritic stainless steel

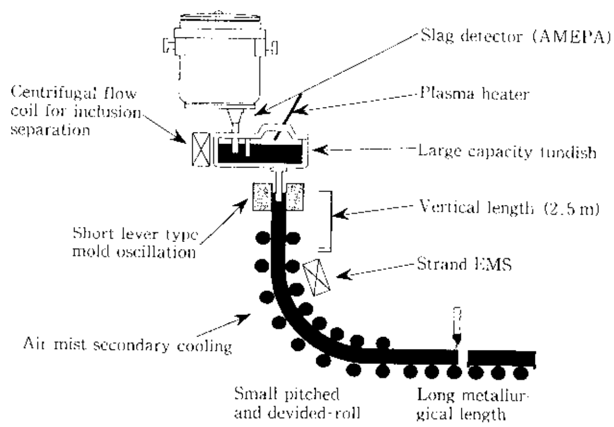


Fig. 9 Schematic illustration of representative facilities in No. 4CCM

speed that surpasses that of VOD of the No. 1 steelmaking shop, which was used exclusively for super ferritic stainless steels, and to increase substantially the productivity of super ferritic stainless steels in the class Cr $\geqq$ 16%, [C] + [N] $\leqq$ 120 ppm.

4.3 Casting Process[2,3)]

4.3.1 Continuous casting equipment (No. 4CC)

To respond to more diverse and stricter quality requirements placed on stainless steels and high carbon steels and, simultaneously, to enable efficient production, particular attention was given to the following three concepts in the construction of No. 4CC.

(1) Improved efficiency of operation (low cost, high efficiency)
(2) Improved quality of slabs
(3) Automation

Figure 9 and **Table 5** show a schematic illustration and the main specifications of No. 4CC, respectively.

When casting stainless steel in large heat sizes of a maximum 185 t/ch with a one strand continuous caster, high-speed casting at 1.6 m/min is essential. In the design of the vertical-bending type continuous caster, which was decided in response to quality requirements, it was necessary to make use of the technologies for slab continuous casters obtained at Chiba and Mizushima Works. In particular, careful attention was paid to the roll design in order to cast stably, on the same machine, products ranging from AISI 316, which has high hot strength, to ferritic stainless steels, which have low hot toughness. To ensure high slab quality, the functions shown in **Table 6** were given to the respective equipment from the ladle to the machine itself. Because the response to small-lot production was also an important point with No. 4CC, the tundish hot recycling technique was adopted to hold down the increase in refractory costs, and quick resetting was made possible by the tundish tilting car, sliding nozzle exchange car, tundish preheating equipment, and other devices. In the area of automation, the response included the adoption of automatic mold powder charging, fully automatic setting of

Table 5 Specifications of No. 4CCM

Item		Specification
Machine type		Vertical bending
Number of strand		1
Metallurgical length	(m)	25.6
Vertical length	(m)	2.5
Curve radius	(m)	9.6
Bending points		7
Unbending points		10
Slab thickness	(mm)	200, 260
Slab width	(mm)	650 ~ 1 650
Slab length	(mm)	4 500 ~ 12 500
Casting speed	(m/min)	Max. 1.6
Tundish capacity	(t)	30
Secondary cooling		Air mist spray

Table 6 Functions installed to improve slab quality

Facilities	Invested functions
Ladle	AMEPA type slag detector Triple-plates sliding nozzle
Tundish	DC twin type plasma heater Large capacity tundish Centrifugal flow tundish
Mold	Twin type eddy current level detector High cycle oscillation
Machine	Vertical bending type (multi-bending and-unbending) Small pitched and devided rolls Air mist secondary cooling Strand EMS

Table 7 Comparison of maximum casting speed between No. 4 and No. 1 CCM

	Maximum casting speed (m/min)	
	No.4 CCM	No.1 CCM
AISI 304	1.6	1.0
AISI 430	1.3	0.9

casting conditions by the process computer, etc. Pooling of operators was achieved by unifying the operation room with the operation room of the existing No. 3CC.

4.3.2 High-speed casting of stainless steel[10]

In the continuous casting of stainless steel, the conventional maximum was 1.0–1.6 m/min. Therefore, to achieve the machine specification of 1.6 m/min, it was necessary to ensure stable casting and reliable quality by developing a total casting technology which includes mold powder, oscillation, mold molten steel level control, secondary cooling conditions, etc. This was done after the startup of No. 4CC, by the following measures:

(1) Optimization of secondary cooling conditions
(2) Optimization of oscillation conditions
(3) Optimization of the spout angle
(4) Adoption of observer control for control of the mold meniscus

As a result, high-temperature slab output was achieved by uniform cooling, sticking was prevented by securing the amount of mold powder consumption, segregation in oscillation mark areas was reduced, and increases in meniscus fluctuations were prevented, realizing stable high-speed casting.

Table 7 shows a comparison of the casting speed with AISI 304 and AISI 430 at No. 4CC and the No. 1CC. Standard production at the world's highest casting speed has become possible with both steel grades.

4.3.3 High cleanliness

In order to achieve high quality in slabs the centrifugal flow tundish (CF tundish) has been introduced as well as the above-mentioned equipment and functions[11].

Because Al-killed stainless steel shows a high ratio of defects caused by alumina inclusions, reducing this ratio is an important task for improving quality. At No. 1CC, the enhancement of separating non-metallic inclusions by applying rotational force to the molten steel flow in the tundish using the linear motor was already confirmed. At No. 4CC, this technique has been introduced.

Figure 10 shows a schematic diagram of the CF tundish which was adopted at No. 4CC. When rotational force is applied by an electromagnetic coil to the molten steel in the rotation chamber, the non-metallic inclusions, which have a low specific gravity, coagulate and are separated at the center. The molten steel then flows

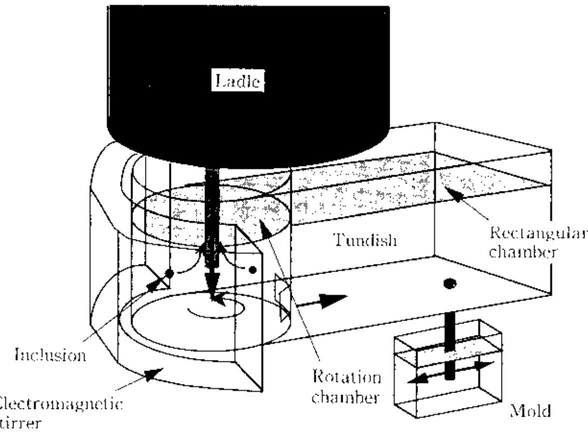


Fig. 10 Schematic illustration of centrifugal flow tundish

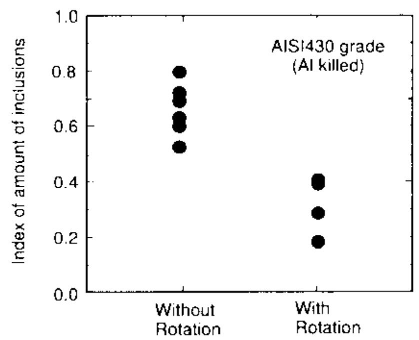


Fig. 11 Effect of rotation in CF tundish on decrease of inclusions in molten steel at rectangular chamber

out into the rectangular chamber, resulting in improved steel cleanliness. As shown in **Fig. 11**, the CF tundish has made it possible to reduce the total oxygen content of molten steel by half.

At No. 4CC, this CF tundish is applied to all Al-killed stainless steel, contributing to improved quality.

4.3.4 Achievement of conditioning-free slabs

At No. 4CC, efforts were made to eliminate the need for slab conditioning by achieving higher molten steel cleanliness using the VOD discussed in the previous chapter and by various quality improvements with the vertical-bending type continuous caster, which was introduced to achieve high slab quality. **Figure 12** shows the trend in the non-conditioning ratio of all stainless steel since No. 1 steelmaking shop and the yield loss ratio attributable to conditioning. Optimization of operating conditions has made it possible to reduce conditioning loss to one-half the former lever.

5 Conclusion

This report has described the concept of the construc-

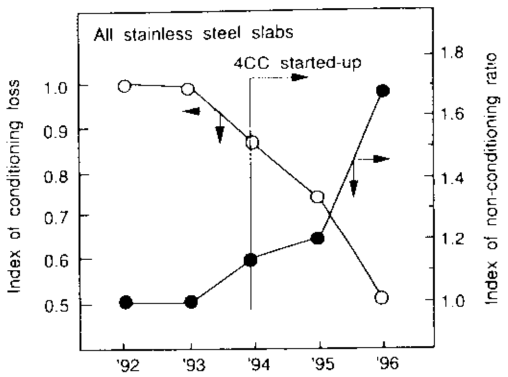


Fig. 12 Trend of conditioning loss and non-conditioning ratio in stainless steel slab

tion of Chiba Works No. 4 steelmaking shop, which was carried out as part of a modernization plan aimed at creating a 21st century environmental-friendly iron and steel works specializing in sheet products, and has presented an outline of the equipment specifications and the condition of operation after startup. Since startup, No. 4 steelmaking shop has continued to operate smoothly. In the future, a rational production system will be constructed by flexible selection of raw materials in response to changing stainless steel raw material prices and further improvement in productivity and quality, making the maximum use of functions of the equipment.

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