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High Speed Continuous Casting Technology for Surface Defects Free Stainless Steel Strand -Construction and Operation of the Chiba NO.4 Continuous Center-

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Synopsis :
At Kawasaki Steel Chiba Works, as part of a modernization program aimed at creating an "urban steel works", No. 4 continuous caster was constructed as a replacement for Chiba's super annuated No. 1 continuous caster. The new caster is used exclusively for speciality steels, centering on stainless, and has functioned smoothly since the start of its operation in July 1994, realizing an improvement in the quality of stainless and high-carbon steel slabs by the introduction of a vertical bending type machine, a larger tundish and other features, and promoting enhancement of productivity by the adoption of automatic equipment.

High Speed Continuous Casting Technology for Surface Defects Free Stainless Steel Strand —Construction and Operation of the Chiba No. 4 Continuous Caster—*

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At Kawasaki Steel Chiba Works, as part of a modernization program aimed at creating an "urban steel works", No. 4 continuous caster was constructed as a replacement for Chiba's super annuated No. 1 continuous caster. The new caster is used exclusively for speciality steels, centering on stainless, and has functioned smoothly since the start of its operation in July 1994, realizing an improvement in the quality of stainless and high-carbon steel slabs by the introduction of a vertical bending type machine, a larger tundish and other features, and promoting enhancement of productivity by the adoption of automatic equipment.

1 Introduction

At Kawasaki Steel's Chiba Works, the construction of a new steelmaking shop and hot strip mill has been carried out as part of a modernization project aimed at creating an "urban steelworks" in anticipation of entrance into the 21st century. In the steelmaking department, a steelmaking shop exclusively for specialty steels, in particular, stainless steels (No. 4 steelmaking shop) was constructed as a replacement for No. 1 steelmaking shop, which has become obsolete. This new steelmaking shop has been operating smoothly since start-up in July 1994. This report highlights the Chiba No. 4 continuous caster (4CCM) among the new facilities in No. 4 steelmaking shop and describes its construction and operation. This continuous caster was constructed to meet the diversifying and increasingly strict quality requirements of stainless steels and high-carbon steels, to ensure efficient operation, and to improve the working environment.

2 General Layout of Steelmaking Shop

The layout of No. 4 steelmaking shop is shown in **Fig. 1**.

No. 4 steelmaking shop was constructed by extending No. 3 steelmaking shop, which produces mainly ordinary steels, to the north side. As shown in **Fig. 2**, the

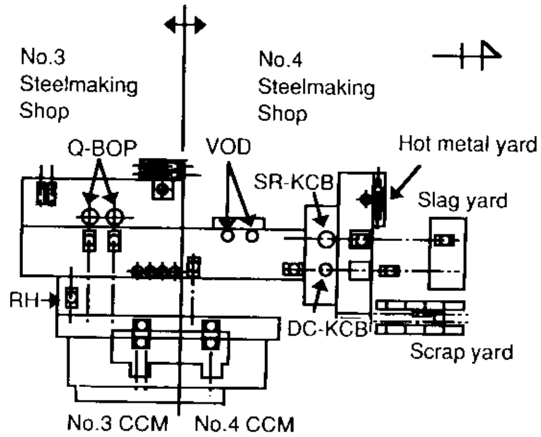

Fig. 1 Layout of steelmaking shop

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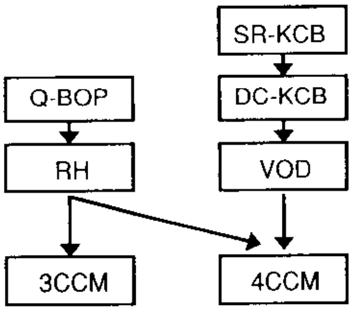

Fig. 2 Process of steelmaking at Chiba Works

ayout of 4CCM is such that, although the shop casts nainly stainless steels and high-carbon steels refined by he process of smelting reduction furnace → decarburizng furnace → VOD, the casting of ordinary steels efined by the existing process of Q-BOP → RH is also ossible. Thus, flexible operation of No. 3 and No. 4 teelmaking shops is possible.

Concept of Construction of 4CCM and Its Equipment Specifications

4CCM was constructed based on the following princial objectives:

1) Increasing productivity by introducing automation equipment

(2) Improving the slab quality of stainless steels (ensuring high quality in both slabs cast under steady conditions and those cast under unsteady conditions)

(3) Coping with small-lot orders

Table 1 Specification of 4CCM and 1CCM

	4 CCM	1 CCM
Machine Type	Vertical -bending	Curved
No. of strand	1	1
Machine length (m)	25.6	19.6
Curve radius (m)	9.6	10.0
Length of vertical strand (m)	2.5	–
Slab width (mm)	650–1 650	700–1 600
Slab thickness (mm)	200, 260	200, 260
Casting speed (m/min)	Max. 1.6	Max. 1.1
Tundish capacity (t)	30	10
Secondary cooling	Air-mist	Flat-spray
Start up	July, 1994	July, 1971

Table 1 shows a comparison of the equipment specification of 4CCM and the No. 1 continuous caster (1CCM) of the existing No. 1 steelmaking shop. The machine length was increased from 19.6 m to 25.6 m in order to accomplish the high-speed casting of stainless steels and high-carbon steels. Furthermore, a roll profile

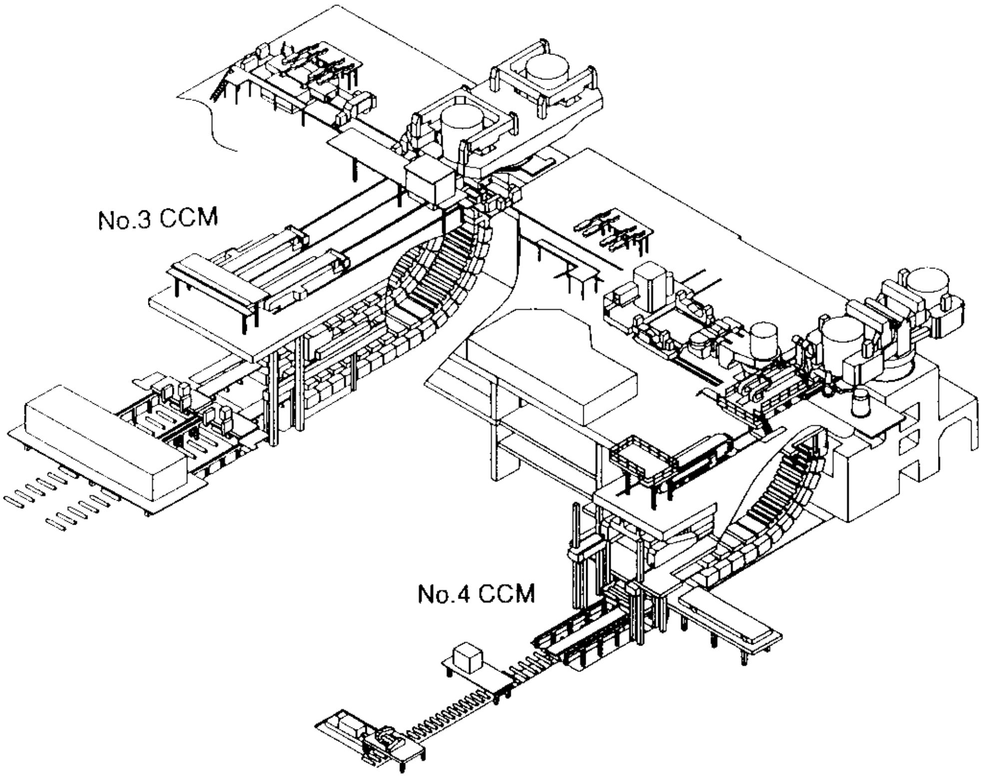

Fig. 3 Schematic view of No. 3 and No. 4 slab caster

of the vertical banding type was adopted and the size of the tundish was increased in order to ensure high slab quality. The layout of 4CCM, which is arranged in parallel with 3CCM, is shown in **Fig. 3**. An independent swiveling type tundish turret was adopted and one tundish preheater, one tundish tilting and deslagging device, and one long nozzle preheater were installed.

4 Features of Equipment and Operation

4.1 Techniques for Automation

The introduction of automation techniques is indispensable for aciheving efficient operation by a small number of operators. The techniques for automation of the casting-floor operation are shown in **Table 2**. Among others, the automatic long-nozzle jointer, automatic mold powder feeder, torch-burr remover, consolidation of operation rooms, and function of automatic setting of casting conditions by a process computer are described below.

4.1.1 Automatic ladle-long nozzle jointer

An outline of the automatic ladle-long nozzle jointer is shown in **Fig. 4**. Automatic positioning is conducted by raising a positioning pin capable of ascent and descent, which is arranged in the long nozzle supporting device, to a positioning block installed in the lower part of ladle-sliding nozzle cassette. The automation of the ladle-long nozzle setting operation that had relied upon operator's visual judgment has been achieved by this technique.

Table 2 Automatic system of No. 4 CCM

Ladle	Automatic connector Long nozzle automatic jointor
Tundish	Submerged nozzle automatic changer Coolant automatic setter Automatic connecto
Mold	Automatic mold powder feeder Automatic mold width changer
	Torch-burr remover

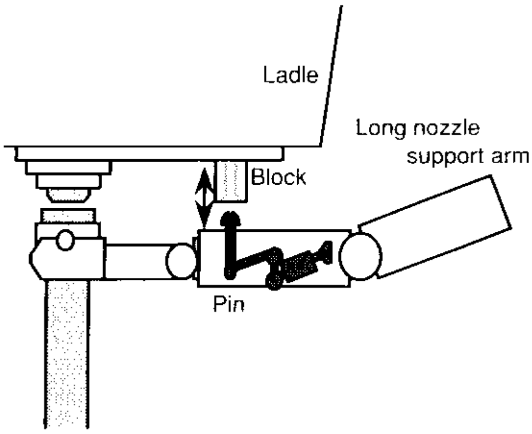

Fig. 4 Long nozzle automatic joint system

4.1.2 Automatic mold powder feeder

An outline of the automatic mold powder feeder is shown in **Fig. 5**. Remote control of automatic travel of the feeder and automatic feeding of mold powder from the central control room is made possible by embedding an electromagnetic induction wire in the casting floor and attaching a positioning sensor to the underside of the mold powder feeder.

4.1.3 Automatic torch-burr remover

An outline of the automatic torch-burr remover is shown in **Fig. 6**. The complete removal of torch-burr is a very important condition for delivering slabs without conditioning to the succeeding process. In this continuous caster, an automatic torch-burr remover of the oscil-

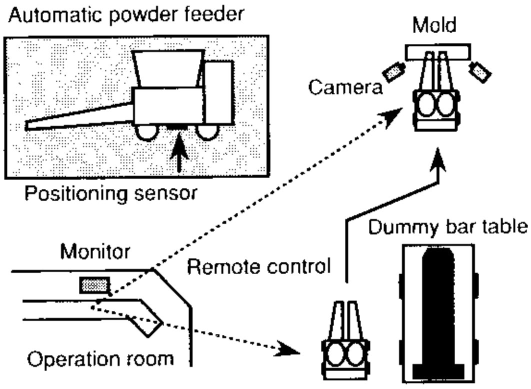

Fig. 5 Powder feeder remote control system

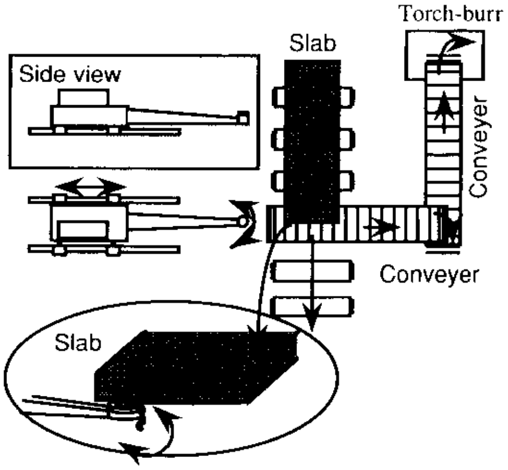

Fig. 6 Outline of torch-burr remover

ating cutter disc type was adopted as a means of completely removing torch-burr with no effect of the shapes of slab edge and torch-burr. It has become possible to ecover the burr and maintain the cutter, etc. without mpeding production by automatically transporting the emoved burr away from the line by conveyor and by naking it possible to move the burr remover from the able line.

4.1.4 Consolidation of operation rooms

The layout of the operation rooms is shown in **Fig. 7**. The casting floor of 4CCM is on the same level to that of 3CCM in order to ensure that the operators of 4CCM can also operate 3CCM (especially during unsteady operation), and the same central operation room is used for 3CCM and 4CCM. Furthermore, the automation of orch cutting control and slab delivery control enabled consolidation of the central operation room and torch operation room (operation by one operator) at 4CCM.

4.1.5 Automatic setting of casting conditions by process computer

To permit operation by a small number of operaors, the consolidation of EICs was carried out to enable centralized operation and monitoring of all facilities using CRTs. Furthermore, because the setting of casting conditions for each steel grade not only increases the operator load but also poses a great problem for quality control and operation mistakes occur, more than 50 casting condition patterns are fully automatically set by the process computer. The flow of setting is shown in **Fig. 8**.

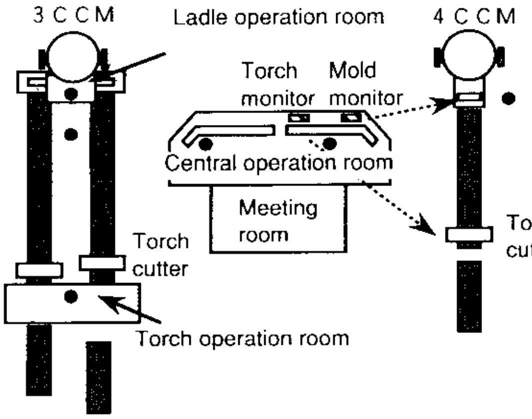

Fig. 7 Layout of No. 3 CCM and No. 4 CCM

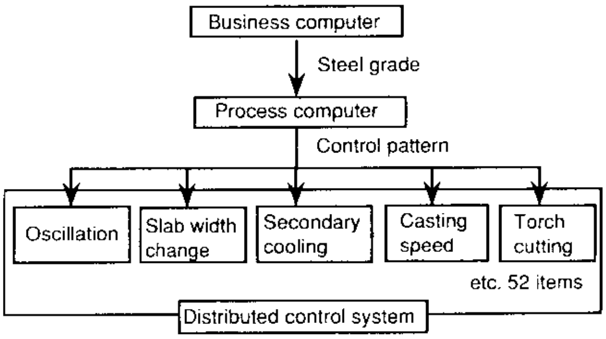

Fig. 8 Outline of No. 4 CCM control system

4.2 Techniques for High-Quality and High-Productivity Slab Casting

4.2.1 Introduction of vertical-bending type continuous caster and large tundish

The existing 1CCM is a curved continuous caster and the tundish capacity is small at 10 t. Therefore, it is not sufficiently effective in floating inclusions and bubbles in the slab, and defects ascribed to inclusions and bubbles (pinholes) have sometimes posed a problem. For this reason, there has so far been no means other than limiting the allocation, throughput, etc. for slabs cast during ladle exchanges.

In new 4CCM, a vertical-bending continuous caster was introduced in order to enhance the floating separation of inclusions and bubbles in stainless steels and high-carbon steels. A section length of 2.5 m was adopted based on a calculation made in consideration of the throughput of stainless steels and high-carbon steels. Furthermore, measures to decrease strain by multi-point bending and multi-point unbending (7-point bending and 10-point unbending) and an increase in roll rigidity by using divided rolls were taken in order to ensure stable casting of steel grades having high sensitivity to surface cracks and internal cracks, such as high-carbon steels.

The caster was designed so that the quality of slabs cast during ladle exchanges is equivalent to that of slabs cast under steady conditions, even in high-speed casting, by increasing the tundish capacity to 30 t. A comparison

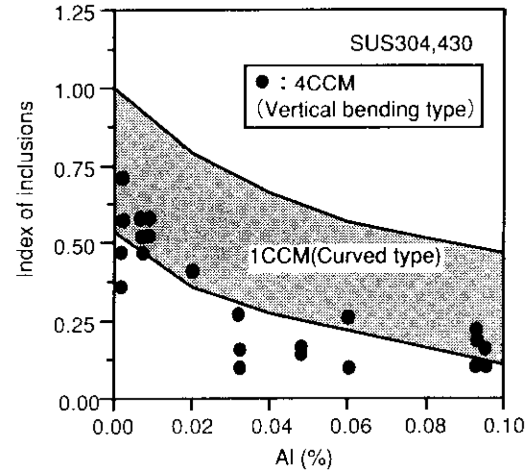

Fig. 9 Comparison of inclusions in slab between No. 4 CCM and No. 1 CCM

of the cleanliness of the molten steel at the two continuous casters is shown in **Fig. 9**.

The index of inclusions at 4CCM is 2/3 to 1/2 that of 1CCM when a comparison is made with the same aluminum content. A comparison of the occurrence of hairpin defects with the two casters is shown in **Fig. 10**. In 4CCM, problems related to hairpin defects have been completely eliminated by the introduction of the vertical-bending type caster. **Figure 11** shows a comparison of the occurrence of hairpin defects on the coil surface with the two continuous casters in slabs cast during ladle exchanges and under steady conditions. The quality of the slabs cast during ladle exchanges reached the same level as that of slabs cast under steady conditions as a result of the increase in the tundish capacity to 30 t, and it has become unnecessary to limit allocation, throughput, etc. For this reason, yield and productivity have increased, contributing greatly to order formation.

4.2.2 Improvement of slab quality by application of centrifugal flow tundish

To meet quality requirements from customers, which have increasingly become severe in recent years, the centrifugal flow (CF) tundish[1,2], one of Kawasaki Steel's unique techniques, was adopted as process equipment for the first time. **Figure 12** shows the relationship between the total oxygen content of molten steel in the ladle and that of molten steel in the tundish. It was ascertained that the total oxygen content of molten steel in the tundish is reduced to half by applying the CF tundish.

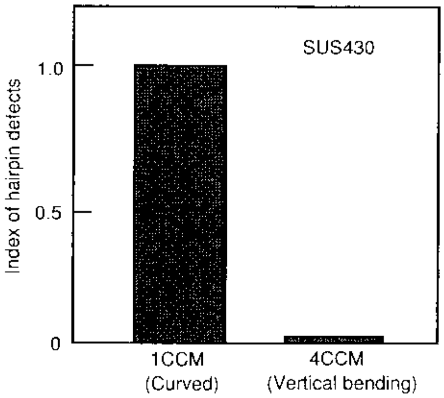

Fig. 10 Comparison of hairpin defects between No. 4 CCM and No. 1 CCM

4.2.3 High-speed casting techniques

Since the existing 1CCM is a curved type caster and the machine length is short at 19.6 m, the maximum casting speed for stainless steels was limited to 0.9 m/min for quality and equipment capacity reasons. In 4CCM, the following improvements in the operation were made in addition to the introduction of a vertical-bending caster and increase in the machine length (25.6 m), and as a result, the maximum casting speed was increased to 1.6 m/min. This resulted in a substantial increase in the productivity of stainless steels[3].

(1) Improvement of Secondary Cooling Method

It has become possible to control the slab surface temperature uniformly in the transverse direction by introducing mist sprays in the whole secondary cooling zone and control of the spray cooling zone edges (upper part: three-stage control of cooling zone edges, lower part: control of cooling zone edges by lowering and lifting the nozzles). **Figure 13** shows the calculated values of the solidified shell thickness and slab surface temperature at the slab center obtained by three-dimensional calculation of solidification and the measured values obtained by riveting and measurement by a radiation thermometer during the casting of SUS 304 at 1.6 m/min. The calculated values are in good agreement with the measured values. Thus, it has become possible, even at a maximum casting speed of 1.6 m/min, to cause the strand to solidify completely within the machine length and produce slabs while maintaining a high surface temperature.

(2) Improvement of Drive Method for Oscillation

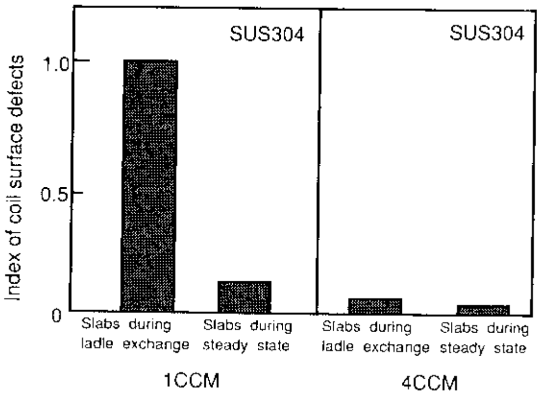

Fig. 11 Comparison of coil surface defects between No. 4 CCM and No. 1 CCM

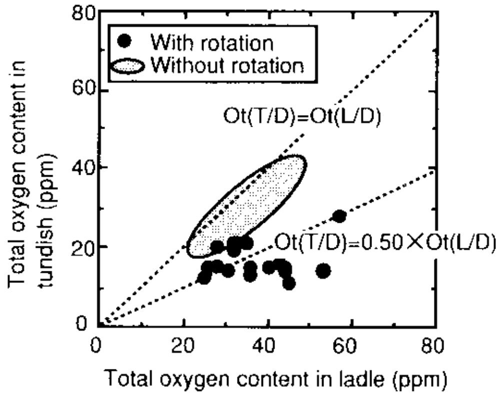

Fig. 12 Relationship between total oxygen content of molten steel in ladle and that in tundish

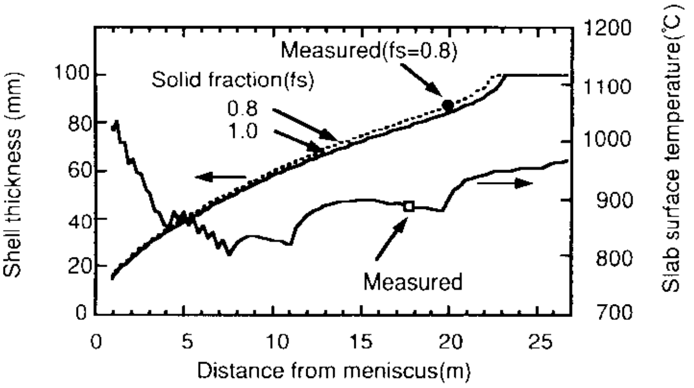

Fig. 13 Shell thickness and slab surface temperature calculated at slab width center (SUS 304 Casting speed 1.6 m/min)

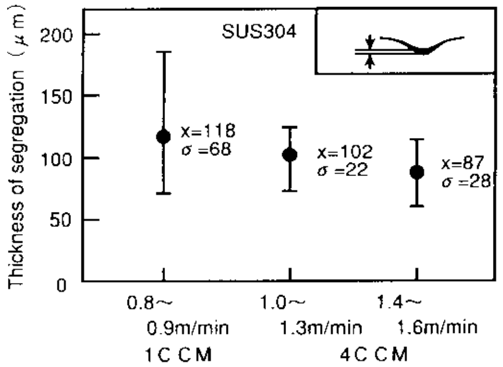

Fig. 14 Comparison of thickness of segregation between No. 4 CCM and No. 1 CCM

Casting under optimum oscillation conditions for each steel grade and speed has become possible due to the adoption of a hydraulic drive type short lever system. **Figure 14** shows the thickness of segregation in the valley of an oscillation mark as a function of casting speed during the casting of SUS 304. It is known that a reduction in the thickness of segregation is effective in reducing the surface defects of SUS 304 coils. In the new continuous caster, it has become possible to reduce the thickness of segregation in the valley of oscillation marks by increasing the casting speed and setting the optimum oscillation conditions, thus contributing to the elimination of the necessity for conditioning SUS 304 slabs and the improvement of slab quality.

3) Improvement of Submerged Nozzle

To prevent the mold powder entrapment that occurs at increased casting speeds, the discharge angle of the submerged nozzle was changed from 5° upward to 35° downward. Because of the increase in casting speed, the surface temperature at the meniscus is the same level as with 1CCM and stable casting has been realized at the maximum casting speed of 1.6 m/min.

4) Introduction of Plasma Heater

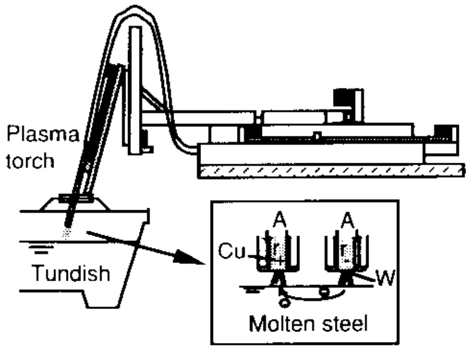

Fig. 15 Outline of the plasma heater

Table 3 Main specification of plasma heater

Tundish capacity (t)	30
Casting speed (m/min)	Max. 1.6
Plasma type	DC transfer Twin torch type
Power (MW)	1.2[3.5 kA×350 V]
Plasma gas	Ar pure(O_2 0.1%)

In 4CCM, a DC twin torch type plasma heater was installed to the molten steel in the tundish in order to ensure stable casting of one strand over an extended period of time[4]. This plasma heater is shown schematically **Fig. 15**. The main specifications of the heater are shown in **Table 3**. A counter electrode on the tundish side is necessary in the single torch type, while an anode torch is used in the twin torch type, and the molten steel is heated by the flow of plasma from the cathode to the molten steel and from the molten steel to the anode. The reasons for the selection of the DC twin torch type are that maintenance of the counter electrode in the tundish is unnecessary and noise is lower than with the AC type (the type

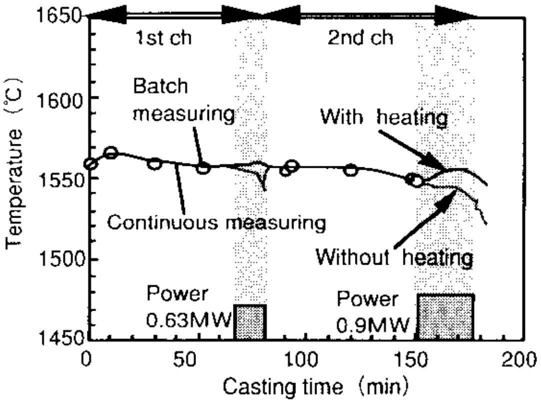

Fig. 16 Effect of plasma heater on temperature of molten steel in tundish

selected is independent equipment and only the torch is maintained).

An example of the transition of the molten steel temperature in the tundish during casting is shown in **Fig. 16**. The molten steel temperature decreases gradually after the start of casting and plasma usually applied in the region immediately before tundish exchanges, when the temperature drop is great. In this figure, the decrease in the molten steel temperature is small in the first charge, which has a relatively short casting time, and great in the second charge, which has a long casting time. Therefore, plasma was applied in the unsteady region from the last stage of casting to the completion of pouring of the molten steel from the tundish. Temperature compensation of about 15°C was made possible by plasma applied at 0.9 MW for 25 min. Thus, it has become possible to conduct stable casting for a long period of time by optimizing the application conditions during plasma heating using the DC twin torch heater.

4.3 Techniques for Coping with Small-Lot Orders

Orders to the steelmaking process have been placed in increasingly small lots year by year because of the diversification of steel grades and kinds of product and to shorten the time of delivery to users. In order to cope with an increase in the number of tundishes used due to small-lot orders, it is possible in 4CCM to reuse tundishes by the hot repair of tundish refractories.

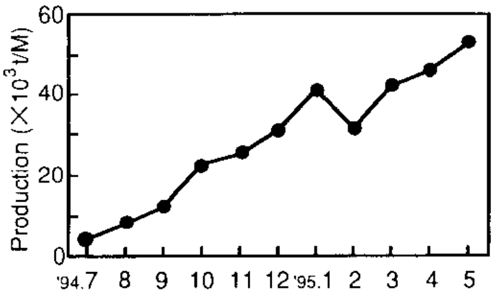

Fig. 17 Trend of production

5 Conclusion

The Chiba No. 4 continuous caster was constructed to meet the diversifying and increasingly strict quality requirements placed on stainless steels and high-carbon steels, to ensure efficient operation, and to improve the working environment. This continuous caster, which started operation in July 1994, is presently operating without problem, and output is increasing smoothly, as shown in **Fig. 17**. The authors intend to improve quality and productivity further in the future by examining the optimum casting conditions for each steel grade.

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