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New Equipment for Improvement of Stainless Steel Casting Quality

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New Equipment for Improvement of Stainless Steel Casting Quality*


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1 Introduction

Molten stainless steels are being processed at low cost from pretreated hot metal obtained through the MF-K-BOP-RH process, which makes full use of the advantages of an integrated steelmaking works. These steels were first produced by continuous casting at the Chiba No. 1 continuous caster in 1974[1]. Production has continued smoothly since that time, and, currently, all molten stainless steels produced by Kawasaki Steel are continuously cast.

The curved type, one strand continuous caster was put into service in 1971 for use in casting specialty steels such as high carbon steels, low carbon steels, and high alloy steels, in addition to stainless steels, as shown in **Table 1**. Taking into consideration the fact that this No. 1 continuous caster thus produces a variety of specialty steels and that heavy slabs 200 mm thick were to be cast on this curved type continuous caster, a major effort was directed toward the improvement of slab quality when stainless steels were first put into continuous casting.

Against this background, this paper deals with the improvements of surface and internal qualities of slabs which have been realized by various approaches, including such new technologies for continuous casting of stainless steels, already developed or presently under development by Kawasaki Steel, as a tundish heating system, the application of flow control techniques to liquid steel in the mold, and the use of high frequency mold oscillation.

2 Establishment of Continuous Casting Techniques for Stainless Steel

2.1 Development of Tundish Heating System[2]

In transient periods such as the start of casting, changes of ladle, and the end of casting, the following

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Table 1 Steel grades cast at Chiba No. 1 continuous caster

Classification		Steel grade
Ferritic stainless steel		SUS 430
Martensitic stainless steel		SUS 410, R 410 DH SUS 420 J1, SUS 420 J2 HCS 16, SUH 409 R 409 SR
Austenitic stainless steel		SUS 304
High carbon steel (C≧0.50%)		SAE 1050-1060, S50C S55C, SK 5, SK 4, SKS 5, SKS 51
Low alloy steel (C<0.50%)	Cr-Mo steel	SCM 415, SCM 435 SCM 440, SAE 4130
	Mn-Cr steel	SMNC 3, SAE 5046
	Ni-Cr-Mo steel	SNCM 220, SAE 8615, SAE 8617, SAE 8620
	Mn steel	SAE 1041, SAE 1041 M
High alloy steel		9% Ni steel

problems are apt to occur:

(1) Decreases in the temperature of the molten steel in the tundish.
(2) Susceptibility of molten metal to reoxidation during teeming from ladle to tundish and from tundish to mold.
(3) Contamination of the molten steel with slags in the ladle or tundish and with mold powder.

In particular, drops in the temperature of the molten steel in the tundish make it difficult to float inclusions in the melt for separation. Therefore, it is indispensable that the temperature of the liquid steel in the tundish be maintained at a certain degree of superheating if slab quality is to be improved, and temperature control techniques for this purpose are extremely important.

2.1.1 Tundish heating system

This tundish heating system employs a channel-type inductor low-frequency induction heating system, which is composed of an inductor, a power supply unit for the inductor, and control unit. The inductor consists of a molten steel channel, for introducing the molten steel, an iron yoke, and a coil for generation of induction current. The inductor is connected to the side wall of the tundish (capacity 7 t) by flanges, as shown in **Fig. 1**. Molten steel is heated by Joule heat developed by the induction current generated in the secondary circuit of the molten steel channel by the application of AC power across the primary coil wound around the iron yoke.

To compensate for the heat absorbed by the tundish refractories at the initial period of casting, a large amount of power must be quickly supplied to the inductor. The heating system, however, should be of small scale from the point of view of economy. After reviewing the heat balance obtained from the results of measurement of the temperature changes of the molten steel in the tundish in normal process charges at the No. 1 continuous caster, an inductor of a max 1070 kW capacity was adopted.

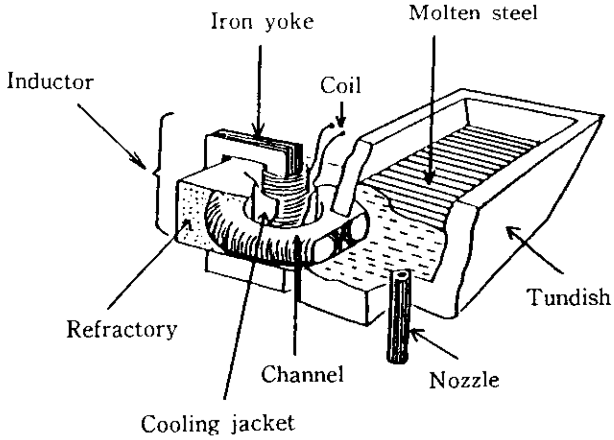


Fig. 1 Schematic view of tundish heater system

2.1.2 Experimental procedure

During the continuous casting of stainless steel, heating experiments were conducted in which the temperature of the molten steel in the tundish was kept constant over the whole period of casting with the aim of preventing the liquid temperature drop which takes place at the start of casting, end of casting, and change of ladle. Experiments were also carried out to study the influence of superheating on slab internal properties by altering the superheating temperature of the molten steel in the tundish during the mid-casting period.

(1) Heating Method
In the early stages of these experiments, the electric current was controlled manually by tap changing. In the later period, an automatic control system using thyristors, now fully developed, and continuous temperature measurement, which has already been put into practical use, were incorporated. The results of application of this technology will be dealt with in detail in a separate paper[3]. The drop in the temperature of the molten steel in the tundish peaks at the start of casting. To cope with this, a system capable of supplying maximum power to the inductor within one minute was introduced. The temperature of the molten steel in the tundish was measured continuously by an immersion type thermometer developed for these experiments.

(2) Experimental Conditions
During the continuous casting of SUS 304 (AISI 304) and SUS 430 (AISI 430), experiments

Table 2 Casting conditions for experiments

	No. 1 CC
Slab size	
Thickness	200 mm
Width	800-1 280 mm
Casting speed	0.8-0.9 m/min
Oscillation condition	
Stroke	2-8 mm
Frequency	60-300 mm

on molten steel heating were repeated approximately 200 times. Operating conditions other than those for heating the molten steel in the tundish are shown in **Table 2**.

(3) Investigation of Slab Quality

A 6 m slab was cut as a specimen from a position corresponding to the three transient periods of casting previously discussed. The distribution of large inclusions and pinholes in subsurface layer (to 20 mm below the surface) arranged in the direction of thickness was determined by the dye penetrant testing method. By the slime extraction method, X-ray fluoroscopy, and oxygen analysis, the amount of inclusions at the accumulating zone in the direction of thickness was examined.

(4) Investigation of Product Coil Quality

The frequency of occurrence of various defects was examined. These defects included slivers and skin-laminations on cold rolled sheets caused by large inclusions in the subsurface layer of the slab and seam defects on cold rolled sheets which originate from large inclusions existing in the accumulating zone in the slab interior.

2.1.3 Optimization of power input pattern in initial stage of casting

To compensate for the drop in temperature of the molten steel in the tundish which takes place at the start of casting, it is necessary to increase the power input to the inductor. When the depth of the molten steel in the tundish is insufficient, however, excess power input will cause electrical instability (pinching), and stable heating of the melt will be impossible. On the other hand, insufficient power input relative to the depth of the molten steel will result in inadequate heating of the molten steel. Electrical stability during heating was evaluated on the basis of current variations detected in the load balancer of the power unit. The occurrence of pinching, together with the attendant increase in secondary resistance and current variations, makes current changes in the load balance conspicuous. With increasing depth of the molten steel in the tundish, it becomes increasingly

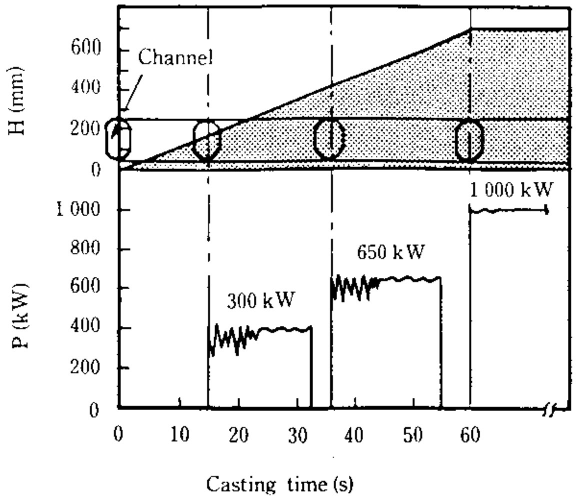


Fig. 2 An example of optimum power input at the start of casting

easier to stably apply large amounts of power. At depths of more than 600 mm, a maximum of 1000 kW can be applied. In the earlier stages of casting, delays in the application of power to the heating unit render heating proportionately less effective. Consequently, power must be applied as earlier as possible.

Figure 2 shows a typical example of the optimum power input pattern for the initial stage of casting, taking into consideration the points mentioned above. The drop in the temperature of the molten steel after application of the tundish heating system in the initial stage of casting was limited to 5°C or less, a noticeable improvement in comparison with the temperature drops of 10 to 20°C in molten steel when no tundish heating system is applied. Furthermore, recovery of proper temperature was rapid when this system was applied. The recovery time was cut to 6 min, less than half the 13 min when no tundish heating system is used.

2.1.4 Heating of molten steel in tundish at change of ladle and end of casting

Figure 3 shows a typical example of the control of

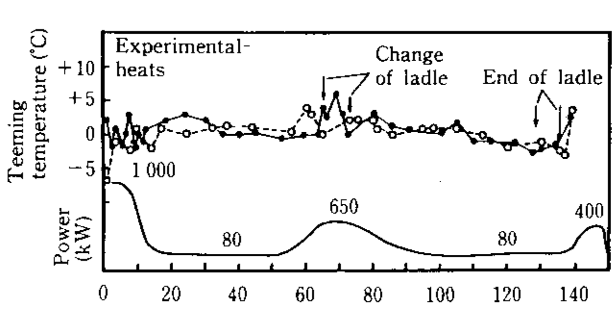


Fig. 3 Temperature change of molten steel in tundish during casting

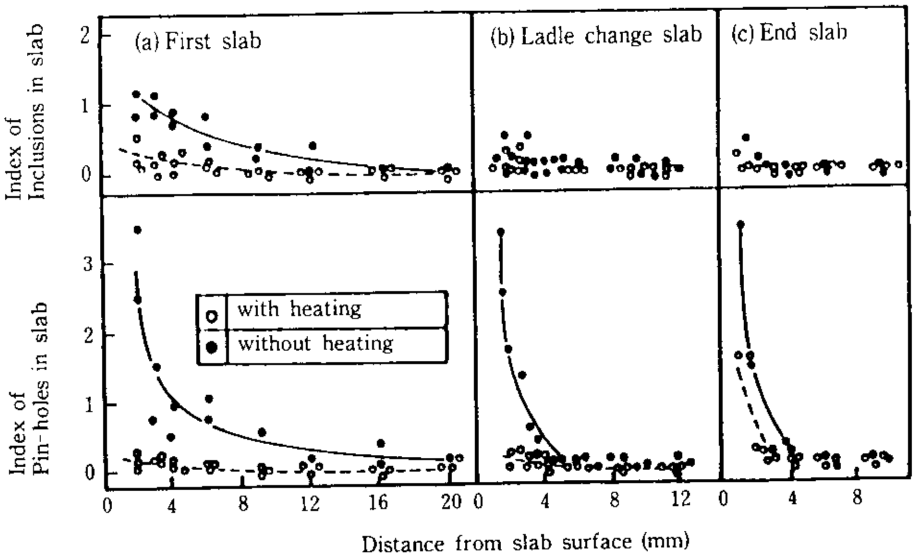


Fig. 4 Decrease of inclusions and pin-holes in SUS 304 slab by tundish heater

the temperature of molten steel to be processed by continuous casting over the whole casting period, including start of casting, change of ladle, and end of casting. Since the drop in the temperature of the molten steel in the tundish at the change of ladle and end of casting is small compared with that at the start of casting, a power input of about 1/2 the maximum level is adequate to prevent these temperature drops.

2.1.5 Improvement of slab quality

Figure 4 illustrates the influence of tundish heating on the distribution of large inclusions and pinholes entrapped in the subsurface layer of a SUS 304 slab cast in the transient stage described above. The application of the molten steel heating process reduces the number of the large inclusions and pinholes in the subsurface layer to 1/4 to 1/12 that with heats cast without tundish heating. In the normal casting process, the effect of tundish heating on the reduction of these defects is noticeable, in particular with slabs cast at the start of casting, when the molten steel temperature drop is large. The application of the tundish heating process improves the surface quality of slabs of steel from transient periods to such an extent that their quality reaches a level equivalent to that of steel from more stable heating periods. This is attributable to the fact that the increase in molten steel temperature at the time of casting improves the fusibility of mold powder and allows the inclusions extrapped in the molten steel in the tundish or mold to rise to the surface and be removed.

2.1.6 Improvement of surface quality of product coils

Defects such as slivers, skin laminations, and seam defects occur, as discussed earlier, on the surface of product coils rolled from slabs of steel from transient stages of casting. The influence of tundish heating on the occurrence of these product coil defects was investigated, with the result that, in about 200 coils of products rolled from the heats to which tundish heating was applied, reductions occurred in every defect. Seam defects, in particular, were virtually eliminated as a remarkable improvement.

2.1.7 Thermal efficiency of inductor

Assuming that the volume of molten steel in tundish is constant, and perfect mixing is assured, the heat balance of molten steel in the tundish is calculated taking into consideration the application of tundish heating, Equation (1) is obtained:

$$\frac{d\,\Delta T}{dt} = -\frac{Q}{W} \times \Delta T + \frac{H_h}{C_p \cdot W} \quad \cdots\cdots\cdots(1)$$

$$\Delta T \equiv T_h - T$$

where,

T_h: Temperature of molten steel in tundish with tundish heating
T: Temperature of molten steel in tundish without tundish heating
Q: Velocity of flow of molten steel into or out of tundish
W: Weight of molten steel in tundish
H_h: Heating energy
C_p: Specific heat of molten steel
t: Time

If $\Delta T = 0$ (elimination of molten steel temperature drop), when $t = t_0$, Equation (2) is obtained:

$$\Delta T = \frac{H_h}{C_p \cdot Q}\left\{1 - \exp\left[-\frac{Q}{W}(t - t_0)\right]\right\} \cdots(2)$$

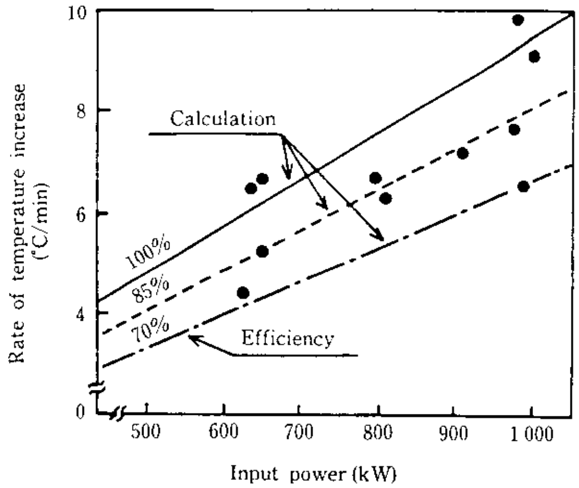


Fig. 5 Heat efficiency of tundish heater

The relation between the calculated values of ΔT obtained from Eq. (2) when $t_0 = 1$ min and the relevant measured values is shown in **Fig. 5**. The thermal efficiency of this tundish heating equipment lies in the range of 75–100%, the average being 85%. Estimating heat dissipation of 10 to 15% to the cooling jacket, the outside wall of the inductor, and the induction coil, a thermal efficiency of 85% may be considered a reasonable value.

2.2 Flow Rate Control of Molten Steel in Tundish

In an attempt to improve the quality of slabs from transient periods, the tundish heating process has been applied. In addition, an electromagnetic brake unit (EMBR)[4] was installed. This unit, a technique for control of the flow speed of the molten steel in the mold, was developed jointly by Kawasaki Steel and ASEA AB.

2.2.1 EMBR equipment

The EMBR is illustrated schematically in **Fig. 6**.

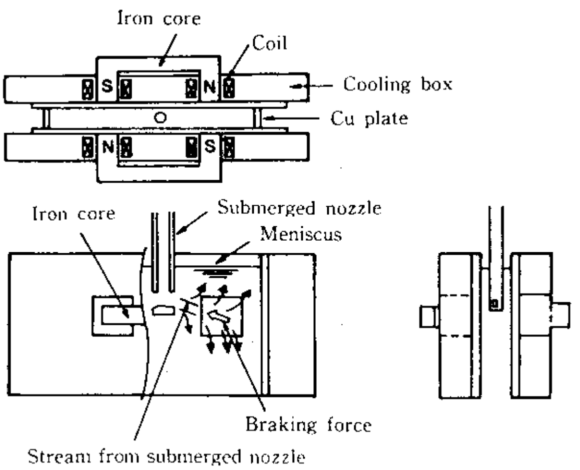


Fig. 6 Schematic representation of the electromagnetic brake, EMBR

Direct current is applied to the four coils installed on the side of the wide face of the mold to generate direct current magnetic flux (static magnetic field) in the mold. The jet stream from the submerged nozzle is decelerated by the braking force produced in the molten steel through interaction with the static magnetic field. This deceleration reduces the speed of impingement of the liquid metal against the solidified shell formed at the narrow face of the mold, as well as the secondary flow speed (ascending and descending flow) occurring after this impingement.

2.2.2 Effect of EMBR on variation of meniscus level in the mold

The variation of meniscus level measured during the continuous casting of SUS 430 was ±1.2 mm when the EMBR was used, a decrease in variation from the ±1.7 mm without the EMBR. The application of the EMBR to decelerate the secondary ascending speed eliminates meniscus movement, leading to a smaller variation in the liquid steel level. For this reason, slabs cast after EMBR application show little oscillation mark agitation.

2.2.3 Effect of EMBR on internal quality of slab

The effect of the EMBR on the internal quality (inclusions and pinholes) of SUS 430 stainless steel slab was examined in a sliced specimen by fluoroscopy. **Figure 7** shows the distribution, in the direction of slab thickness, of defects ("B spots") larger than 100 μm as detected by fluoroscopy. When EMBR is not applied, a 1/4 thickness B spot accumulating zone forms; this is a well-known characteristic of the curved type continuous

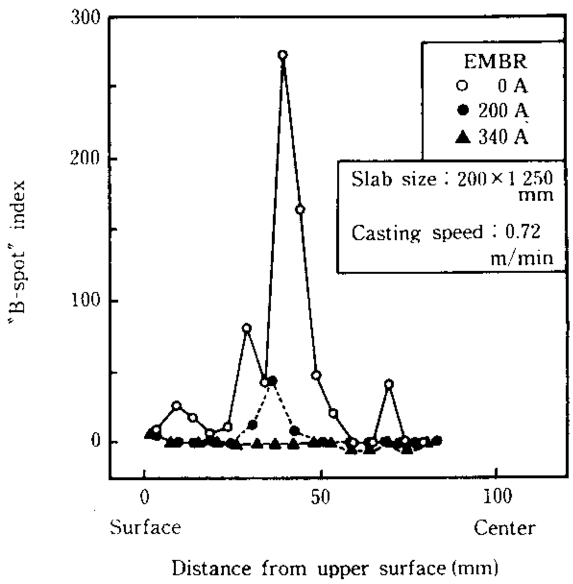


Fig. 7 Effect of EMBR on the "B-spots" distribution

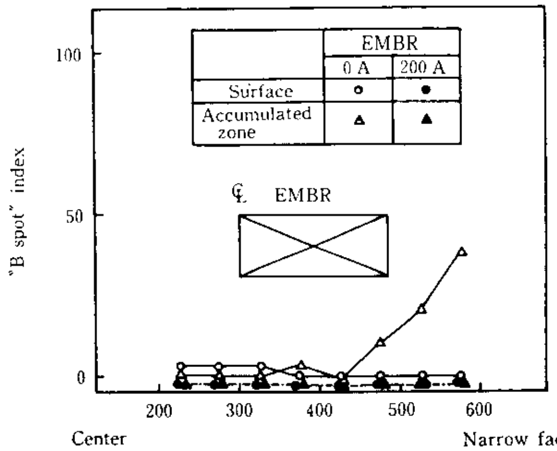


Fig. 8 Decrease of "B-spot" by EMBR

caster. The application of EMBR markedly reduces this accumulating zone or eliminates it entirely.

Figure 8 shows the width-wise distribution of the 1/4 thickness B spot accumulating zone of a SUS 304 stainless steel slab. When the EMBR is not applied, an increase in B spots is observed at the narrow face. When the EMBR is applied, however, the occurrence of B spots at the narrow face is practically undetectable.

Observation by optical microscopy of these B spots revealed that 99% of the spots were bubbles. These bubbles were of Ar gas injected through the nozzle during casting and entrapped in the slab. The properties of product coils of the heat to which the EMBR was applied are presently being given confirmation examinations, with favorable results being obtained.

2.3 Application of High Frequency Mold Oscillation

Oscillation marks on the slab surface cause transverse facial cracks, corner cracks, positive segregation, scums, and entrapment of inclusions in the subsurface layer[5-14]. With stainless steel, which shows less scale formation during slab reheating, oscillation marks are not eliminated, and tend to cause defects in the cold rolled strip[6, 11].

With increasing frequency of cycles, f, and shorter stroke s, the depth of oscillation marks, d, is reduced, as shown in **Fig. 9**. To decrease the depth of the nail-like shell which forms at oscillation marks, it is necessary to reduce the negative stripping time t_N, expressed in Eq. (3), by reducing s and/or increasing f:

$$t_N = \frac{1}{\pi f} \arccos\left(\frac{u}{\pi f s}\right) \quad \cdots\cdots (3)$$

where,

u: Casting speed

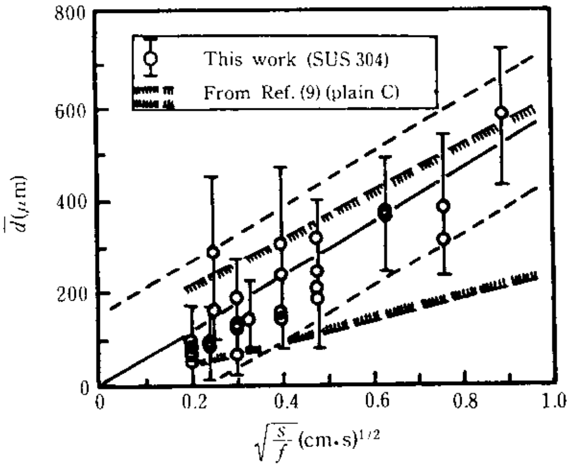


Fig. 9 Effect of mold oscillation on the mark depth of slabs

2.3.1 Modification of mold oscillation equipment

As the mechanism for mold oscillation at the No. 1 continuous caster, a seazus mechanism was initially adopted. This mechanism, being low in vibration system rigidity, caused violent lateral vibration (horizontal vibration) at frequencies exceeding 130 cycle/min, and thus made it difficult to employ high frequency mold oscillation. As a countermeasure against this lateral vibration, a short lever mechanism was freshly adopted. The device is capable of generating an oscillation of 400 cycle/min, the maximum value of the oscillating mechanism for continuous casing machines in the earlier period of casting. At the same time, modification to enhance rigidity was carried out.

2.3.2 Experimental procedure

The experimental conditions for oscillation equipment are shown in Table 2. In the following Eq. (4), N is defined as the negative stripping ratio of an expression of average speed. In conducting the experiment, s is set smaller (shorter) with increasing values (higher values) of f, so that N is always positive.

$$N = \frac{2sf}{u} - 1 \quad \cdots\cdots (4)$$

Slabs used in these experiments were examined to determine the depth and pitch of the oscillation marks and to observe the solidification structures, nail-like shell, and segregation, in addition to examination of their surface quality as as-cast slab by visual observation. Further, to examine the distribution of entrapped scums and large inclusions in the subsurface layer of the slab, dye penetration tests were conducted after grinding.

2.3.3 The Effects of mold oscillation conditions on the depth and pitch of oscillation marks

As indicated in the theoretical analysis reported elsewhere [13], oscillation marks are formed by the molten slag which pushes forward frozen shell toward the molten steel. This molten slag is forced to flow into the inlet slit at the meniscus in the mold when negative stripping is carried out. Thus, as shown in Fig. 9, the application of high frequency mold oscillation makes oscillation marks shallower. Its use, as are shown in **Figs. 10** and **11** and **Photo 1**, not only makes nail-like shell shallower but also reduces its frequency of occurrence. The shape of the nail-like shell has thus been markedly improved, and in turn brings about a reduction of the depth, the area of occurrence, and the formation frequency of positive segregation [5,6,11] at the oscillation marks. As is obvious from Fig. 11, SUS 304 and SUS 430 differ in the dependency on oscillation condition of their rates of nail-like shell formation. This is due to differences in the strength of the solidified shell of the materials at the meniscus in the mold. As is suggested by Takeuchi et al.[6], the rolling without surface conditioning of slab will sometimes allow this positive segregation to remain on the rolled product, presenting a pattern. Therefore, it is necessary either to prevent the occurrence of positive segregation or to make it as shallow as possible by improving the nail-like shell condition through application of high frequency oscillation.

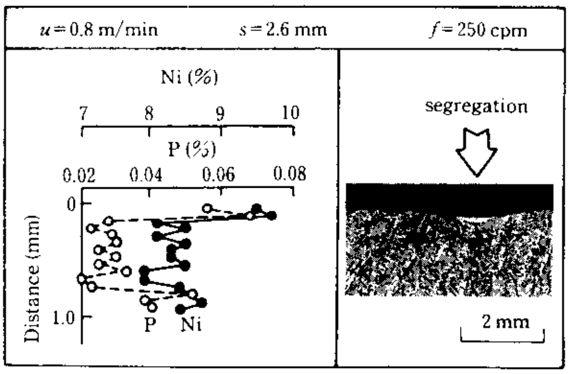


Photo 1 Phosphorus and nickel segregation of oscillation mark (SUS 304)

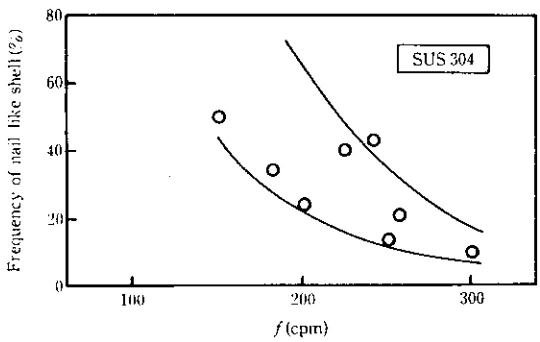


Fig. 10 Effect of mold oscillation on the frequency of nail-like shell formation

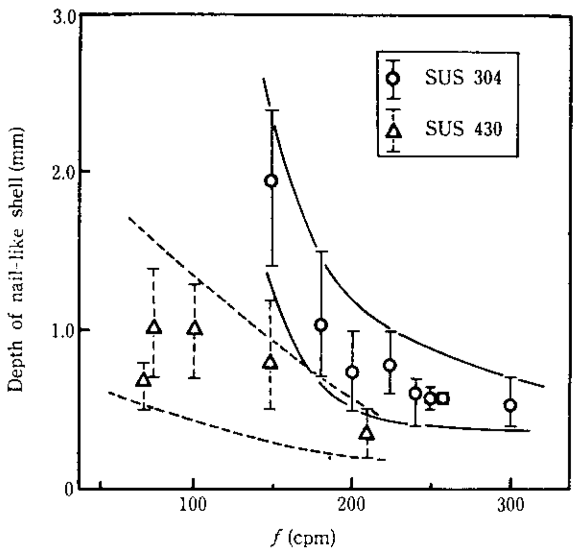


Fig. 11 Effect of mold oscillation on the depth of nail-like shell

The measurement values of pitch of oscillation marks, l', are distributed around the theoretical value l ($\equiv u/f$), and sometimes become $l' \gg l$, resulting in the disappearance of oscillation marks in positions where they should be located. Oscillation marks, even if formed under the same conditions, become increasingly deep with increasing l'. The disappearance of oscillation marks is attributed to the decrease or elimination of real negative stripping time at the meniscus caused by minute variations in the level of the meniscus[14]. When oscillation marks disappear, not only the effect of application of high frequency mold oscillation decreases but the slag inflow from the meniscus into shell/mold boundary also becomes non-uniform. Therefore, it is necessary to reduce the deviation and frequency of meniscus level fluctuation.

2.3.4 Effects of mold oscillation conditions on entrapped scums and subsurface inclusions in continuously cast slab

The effect of mold oscillation conditions on scum index (frequency of occurrence of scums and large inclusions) of the slab subsurface layer is shown in **Fig. 12**. Scum defects which can be detected by dye penetration tests are reduced by the application of high frequency mold oscillation. In the case of SUS 304 slabs, if $f \geq 200$ cpm, scum defects can be reduced to less than 1/2 that with conventional $f = 130$ cpm. **Figure 13** shows the results of an investigation of scum defects in the sub-

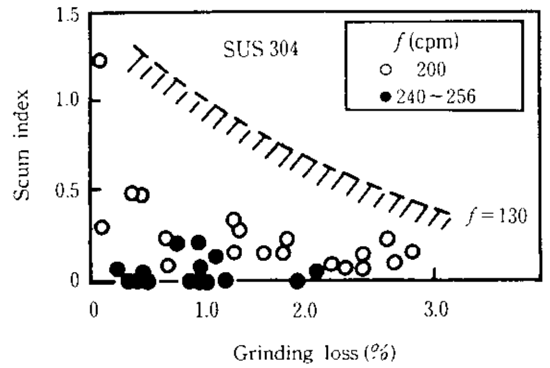


Fig. 12 Improvement of surface quality of slabs by high cycle oscillation casting

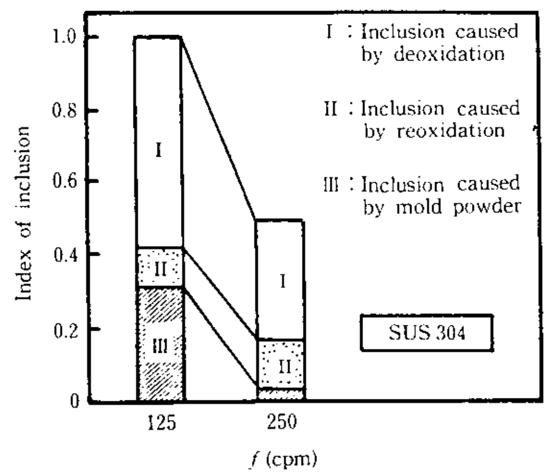


Fig. 13 Decrease of slab surface inclusions by high cycle oscillation casting

surface layer of SUS 304 slabs, classified by cause. High frequency mold oscillation contributes to the marked reduction of inclusions which is attributed to continuous casting powder and deoxidation products. This is because the improvement of the shape of nail-like shell means that scums and other inclusions are less easily captured. Furthermore, the application of high frequency mold oscillation entails a shorter stroke, and it is considered that this affords a lower relative ratio of mold descent distance to the thickness of the molten slag layer on the surface of liquid steel, thereby reducing the likelihood of capture of particle, sintered, or half molten layers of powder in the meniscus.

2.3.5 Techniques supporting high efficiency, stable casting

The mold lubrication monitoring system monitors the condition of lubrication in the mold during casting by means of pin-type load cells[15] and embedded thermocouples developed by Kawasaki Steel. Experiments with this system are now underway with interesting findings obtained in regard to mold lubrication. These findings are already contributing to stable casting with the No. 1 continuous caster.

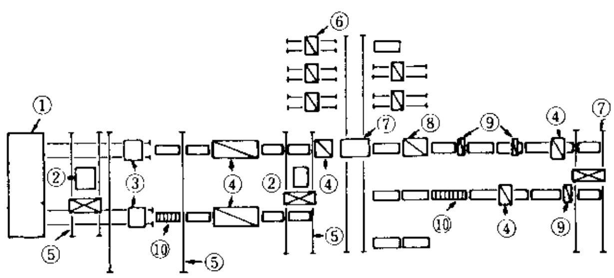
Sequential continuous casting, on the other hand, is effective in the reduction of the transient periods discussed earlier and of various unit consumptions such as that of refractories. In the continuous casting of stainless steel where small lot, multi-product production is mandatory, execution of continuous width changing provides high operational efficiency and improved slab quality. The latest casting tonnage per tundish reaches an average of 270 t.

3 Operation of New Conditioning Yard and Increase in Efficiency of Surface Conditioning

3.1 Description of New Conditioning Yard

A new conditioning yard was constructed to allow a drastic rationalization of slab conditioning by integrating conditioning yards previously scattered over three locations within the East Plant of the Chiba Works, and at the same time, to realize the improvement of slab surface quality with enhanced yield control. This new yard went into operation in August 1984.

The surface quality of stainless steel slabs has been improved to a large extent by the development and improvement of the related techniques already discussed. The operation of this yard has further raised the confidence level for slab quality. Among other factors, the automation of slab grinders and the introduction of slab shot blasting equipment have brought about a uniformity of surface roughness in product to be charged into the reheating furnace for hot rolling, contributing greatly to higher coil surface quality. In addition, the introduction of online computers connected directly to



1 Cold scurfing machine
2 Turnover
3 Scurfing transfer car
4 Spot grinder
5 Loader
6 Overall grinder
7 Turnover/traverser
8 Shot blasting machine
9 Penetrating test machine
10 Weighing machine

Fig. 14 Layout of new conditioning shop

Table 3 Specifications of conditioning machines for specialty steel

Machine	Specifications
Overall grinding machine	Gate type, over head style Grinding wheel: 610 mmϕ Grinding speed: 4 800 m/min (max) Grinding angle: 45° Motor: AC 110 kW Traverse car: hydraulically-operated winch type
Spot grinding machine	Gate type, over head style Grinding wheel: 305 mmϕ Grinding speed: 3 800 m/min (max) Grinding angle: 90° Motor: AC 15 kW
Turn-over traverser	Cradle type with lifting arms and table roller
Shot blast machine	Blasting density: 450 kg/m² (at 1.5 m/min) Traverse speed: 0.5~4.0 m/min
Penetrating test machine	Over head auto-spray type with slab width detecting device

the continuous casting plant and the quality control sector has made it possible to quickly analyze and cope with variations in slab and coil quality.

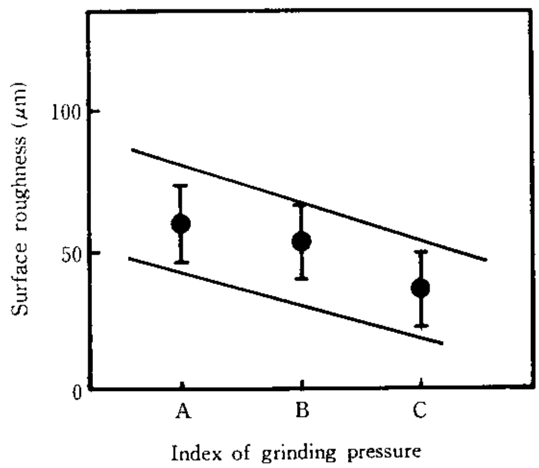
The layout of the new conditioning yard is shown in **Fig. 14**; equipment specifications of the specialty steel and stainless steel line are described in **Table 3**.

3.2 Effect of Conditioning on Surface Quality of Stainless Steel

Stainless steels produce smaller amount of oxidized scale when heated in a reheating furnace for hot rolling than plain carbon steels, and the surface condition of slabs directly governs the surface quality of the products. These points are especially important with austenitic stainless steel. To obtain stabilized surface quality in products, full attention must be paid to the control of surface roughness and flatness when conditioning slabs.

Taking into consideration these points requiring special care, a pressure control technique in which a power-level control device regulates grinding wheel pressure was incorporated in the slab grinder in the new conditioning yard. The introduction of this control method guarantees predictable amounts of grinding loss by ensuring constant proper pressure, even when slipping occurs between the slab and the grinder wheel. The adoption of this method and the automation of the travelling pitch of the grinding wheel have contributed to the reduction of variations in conditioning and to the uniformity of surface roughness. The relation between grinding pressure and surface roughness is shown in **Fig. 15**. The incorporation of the parameter of grinding pressure into grinding specifications using the relation mentioned above has made possible easy control of slab surface roughness.

Shot blast treatment of the slab surface is effective in reducing defects originating in the intergranular cracking which occurs during hot rolling. The hardness distribution of the slab surface after shot blasting is shown in **Fig. 16**. The hardness of the area directly under the surface has markedly increased. Such work strain promotes recrystallization in hot rolling, and this, in turn, is considered to improve hot workability. Moreover, shot blasting has a noticeable effect on the reduction of surface roughness, making it possible to control surface roughness at more uniform, lower levels. **Figure 17** shows the relation between hot coil surface defects and actions taken at the conditioning yard. Even if stable



A: 100% of a rated current with oscillation 3°
B: 100% of a rated current
C: 50% of a rated current

Fig. 15 Effect of grinding pressure on the surface roughness of slab

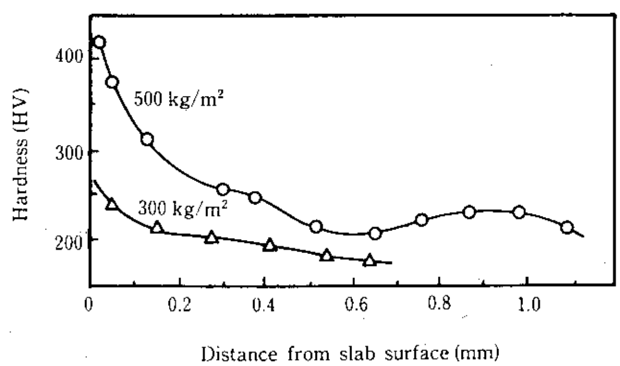


Fig. 16 Hardness distribution of slab after shot blast

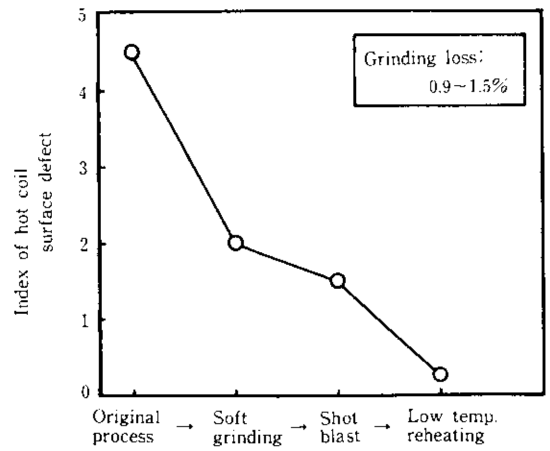


Fig. 17 Improvement of hot coil quality by new conditioning machines

grinding loss values are assured, the ratio of occurrence of hot coil surface defects varies with the method of conditioning. This suggests the importance of operational control in the slab conditioning sector.

3.3 Reduction and Elimination of Slab Surface

The necessary grinding loss for the conditioning of continuously cast slabs of stainless steels has markedly decreased with improvements in continuous casting conditions, contributing to the improvement of yield. Kawasaki Steel has producted its entire stainless steel output by the continuous casting method since all stainless steel facilities were transferred to its Chiba Works. Over this period, slab quality has improved, and progress has been particularly outstanding since the introduction of high frequency oscillation. The introduction of the online computer system in the operation of the new conditioning yard has helped to establish a control system in which the relationship between conditioning instructions and actual results is appropriately ascertained. Thus, grinding loss has decreased while product quality has been maintained at desired levels.

For the purpose of determining the minimum necessary grinding loss for conditioning in consideration of current slab quality requirements, rolling experiments on conditioning-free slabs are now being attempted on a manufacturing-process scale, with favorable results. Experiments are now underway under the fundamental principle that no grinding be performed on slabs through to final products. These experiments reveal that to expand the range of hot rolling without surface slab conditioning, it is important not only to improve slab quality by optimizing casting temperature using the tundish heating process, by improving oscillation conditions, and by implementing shot blasting, but also to take countermeasures to stabilize slab quality by consistently controlling heating temperature, oxygen concentration in the atmosphere, and holding time in the hot rolling reheating furnace.

4 Conclusions

The development of new continuous casting techniques and attendant improvement in the quality of stainless steel slabs mainly comprising SUS 304 and SUS 430 have been dealt with in this paper. The development of tundish heating equipment and the application of high frequency mold oscillation have improved both the surface and the internal quality of stainless steel slabs remarkably. Furthermore, the operation of the new conditioning yard has contributed to the optimization and higher efficiency of slab surface conditioning, and the implementation of continuous width changing has reduced transient periods in casting, with an accompanying increase in operational efficiency.

The control of the flow speed of molten steel in the mold by EMBR and the mold lubrication monitoring system, now in the experimental stage, are providing important information in relation to the quality assurance and stabilized casting associated with high efficiency continuous casting.

The application of these novel continuous casting techniques has greatly contributed to the reduction of grinding loss in the slab surface conditioning stage and to the improvement of product hot coil quality. Experiments being carried out on a large scale on reheater charging and rolling of conditioning-free slabs are also showing satisfactory results.

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