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# Development of Thin Slab Caster*


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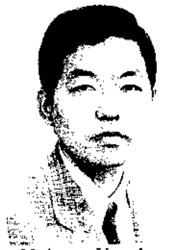

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## 1 Introduction

The continuous casting of steel is a very effective means of saving energy, streamlining manufacturing processes, and increasing steel product yield. As such, it is a representative technology supporting high-efficiency production. Steel engineers have been establishing techniques for directly charging high-temperature slabs obtained by continuous casting into reheating furnaces[1-3] and what is called the hot direct rolling technique[4-6], in which high-temperature slabs are delivered directly to the hot rolling process, omitting the conventional step of charging into the reheating furnace.

In recent years, research and development on thin slab casting and strip casting have been actively pursued with the aim of realizing a next-generation casting technology in which the casting process is directly coupled to the rolling process and synchronized operation of the two processes is possible.[7-12] In the continuous casting of thin slabs, the rough rolling process in hot rolling is omitted, while, in strip casting, the finishing process in hot rolling and even the cold rolling process as such are omitted.

In a strip caster, slabs excellent in both internal and surface quality are required because the slab thickness is close to the product thickness and total reduction in the rolling process is low. Further, many technical problems must be solved to ensure productivity matched to current output requirements. Currently, therefore, the development of strip casting is centered on stainless steel and steels in which rolling from slab is difficult.

On the other hand, the development of thin slab casting for the mass production of plain carbon steels is also under way. In a thin slab casting, however, it is necessary that the casting speed be several times to more than ten times as high as in the conventional continuous casting process. In this connection, because the solidified shell of the slab is susceptible to breakout in the fixed mold due to friction between the mold and the cast material,[13] a moving mold is frequently adopted. There are many types of moving molds: the single block type[14], in which a number of trough-like blocks are connected into one piece, the twin block type[15,16], as in Alusuisse

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Caster II[17], which is used in aluminum casting, the inclined twin belt type[18-22], similar to that of the Hazelett continuous caster[23,24], which is frequently used to cast nonferrous metals, the vertical twin belt type [24,25], and others. Examples of fixed molds include the funnel-shaped mold[26] and the rectangular-section mold[27], as is used in the conventional continuous casting of steel.

Because it is necessary to obtain good surface properties in thin slab casting, as it of course is with the conventional continuous caster, establishing a molten steel pouring technique which will ensure a stable meniscus level is a critical technical problem. To solve this problem, Kawasaki Steel Corp. and Hitachi Ltd. carried out joint research and development of a twin belt type thin slab caster (KH caster), which employs a vertical V-bell mouth mold into which molten metal can be poured using the immersion nozzle method technically established with the conventional continuous caster. In the KH caster, the thin slab is coiled at the delivery side and then conveyed to the finishing mill, where it is hot rolled without reheating. This report describes the features of the KH caster, and gives an outline of the equipment, results of operation, quality of slabs, and quality of final products obtained by hot direct rolling without reheating. It also describes in detail the cooling characteristics of the high-speed water film cooling system which is one of the features of this casting process.

## 2 Features of KH Caster[28]

To obtain good slab quality, especially slab surface quality equal to or better than that with conventional continuous casting, a vertical V-bell mouth mold was adopted in the KH caster so that non-oxidized molten steel feed and stable control of the meniscus level during pouring can be achieved using the conventional continuous casting immersion nozzle. This pouring method is referred to here as the "V-bell mouth mold pouring method." This method is advantageous in terms of the flotation of inclusions and bubbles because a vertical mold is used, and because accumulation bands of inclusions and bubbles do not form.

The two wide faces of the mold are of a belt construction, and move at a rate equal to the slab withdrawal speed, making possible high-speed casting. To ensure uniform total cooling of the slab, a belt cooling system was devised. Where the belt is in contact with the slab, no mechanical support is required, because cooling water flowes at the back of the belt forming a water film, the pressure of which supports the belt. This cooling method is referred to as the "high-speed water film cooling system."

### 2.1 V-Bell Mouth Mold Pouring Method

In the V-bell mouth mold pouring method, the mold width in the direction of slab thickness is large at the top of the mold and decreases gradually toward the bottom of the mold. Thus, as the material being cast moves downward through the mold, its thickness is progressively reduced until the desired slab thickness is obtained. The mold construction is shown schematically in **Fig. 1**. This pouring method allows use of the conventional immersion nozzle. Further, because the meniscus area is almost as large as in the conventional continuous caster, the effect of variations in the flow rate of the molten steel being poured on the mold bath level is small, and the mold bath level is easily controlled.

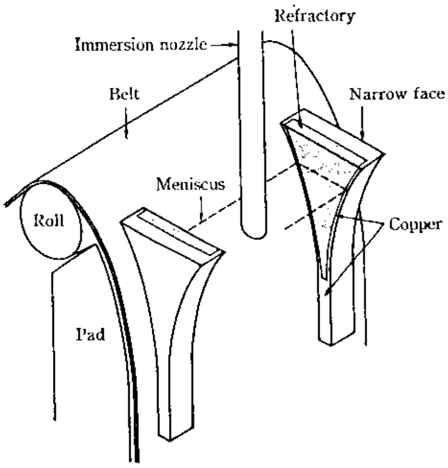

Fig. 1 Schematic drawing of mold construction

The narrow faces of the mold are fixed and set between the twin belts. At the broader upper section of the mold, where the slab thickness is reduced, the narrow faces are protected by refractories and are of a heat-insulated construction, preventing the growth of the solidified shell at the narrow faces of the slab. This construction makes it possible to properly square the solidified shell at the wide faces, where the cast material initially takes on as arc shape. In the upper section, a shell initially forms only at the wide faces, which are cooled by the belt surface. Formation of the shell at the narrow faces begins in the copper-plated section below the refractory-covered area. In other words, the shell begins to solidify at different points at the wide faces and at the narrow faces.

### 2.2 High-Speed Water Film Cooling System

The method of belt support and cooling is schematically shown in **Fig. 2**. Cooling pads with numerous water inlet and outlet holes are positioned at the back of the belt to produce a film of water flowing at high speed between the belt and the pads. The belt is cooled by this water film and, at the same time, is "floated" from the pad face by the water pressure. The significant point in controlling this water film cooling system is to ensure that the ferrostatic pressure and the water film

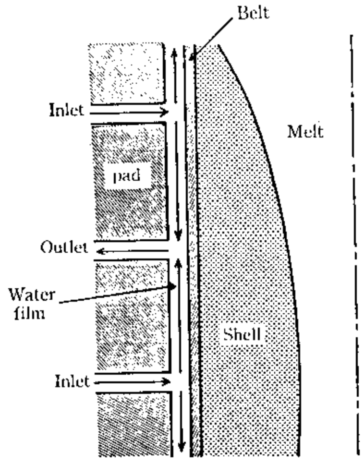


Fig. 2 Schematic view of cooling method with water film

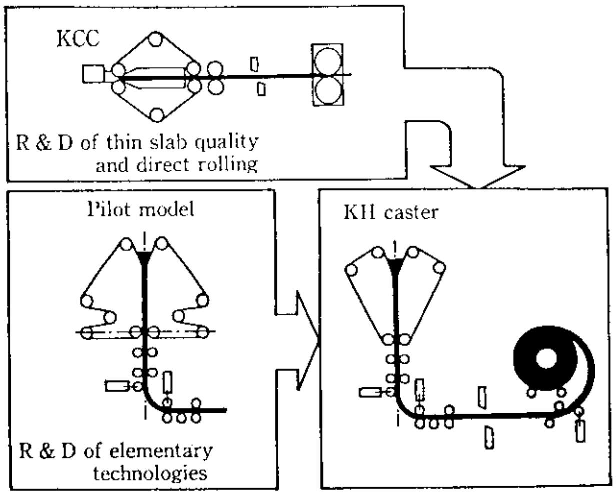


Fig. 3 Step of R & D of KH caster

pressure are in constant balance through the belt at a certain water film thickness while the flow velocity necessary for cooling is also obtained. The diameter of the water inlet and outlet holes, as well as the flow rate of the cooling water, were determined so that these conditions would be met. The velocity of water film flow was designed to hold belt temperature increases below a maximum permissible limit; the water film thickness, on the other hand, was determined so as to compensate for vibrations and deformations of the belt while the flow rate is maintained within an appropriate range.

The features of this cooling system are summarized as follows:

(1) Uniform cooling of the belt and the entire solidified shell surface of the slab is accomplished by a water film.
(2) Uniform support of the belt and of the material surface is ensured by maintaining an appropriate water film pressure.
(3) Liquid lubrication is effected by the water film between the cooling pad and the belt.
(4) A high cooling capacity is obtained by the water film flow.

This cooling system has made it possible to prevent wear and thermal deformation of the belt and to produce slabs which are free from local bulging and have a uniform thickness.

## 3 Process of Research and Development

The progress of research and development related to the KH caster is outlined in **Fig. 3**. A small-scale horizontal thin slab caster (KCC)[29-33] provided with a 200-kg induction melting furnace was constructed in direct connection with a 300-t rolling force hot rolling mill. An investigation was made into the mechanical properties of rolled products obtained by the hot direct rolling of thin slabs[34]. Results of this investigation were as follows:

(1) Yield strength, tensile strength, and elongation increased with increasing total reduction in hot rolling.
(2) When thin slabs 30 mm in thickness are used, the same mechanical properties as with conventional hot rolled products can be obtained at a total hot rolling reduction of 75 to 85% or more.

Further, to ascertain the basic characteristics of the V-bell mouth mold and the high-speed water film cooling system, a prototype vertical thin slab caster with a 5-t molten steel capacity was constructed; casting tests were conducted and techniques in various engineering fields were developed. The main specifications of this continuous caster are shown in **Table 1**. The following findings were obtained:

Table 1 Specifications of pilot model caster

| | |
|---|---|
| Ladle capacity | 5 t |
| Tundish capacity | 2 t |
| Slab size | |
| Thickness | 30 mm |
| Width | 500-600 mm |
| Mold length | 1.65 m |
| Casting speed | max. 5.3 m/min |

(1) The optimization of the shape and material for the narrow faces of the mold makes adoption of the V-bell mouth mold pouring method possible.
(2) Metal penetration into the sliding parts between the belt and narrow faces can be prevented by optimizing the shape of the narrow faces and cooling pads.
(3) The thermal deformation of the belt is reduced by

improving the water film cooling pads; this minimizes slab thickness deviation.

(4) The slab surface is smooth and free from center segregation and accumulation of inclusions.

On the basis of these results, a larger-scale KH caster was constructed and commercial-scale experiments were begun.

## 4 Equipment and Operation of KH Caster[35]

The applicability of the KH caster to the continuous casting of thin slabs was demonstrated in experiments conducted using the prototype thin slab caster. An industrial-scale KH caster capable of casting a large volume of wide slabs at high speed was next installed at the No. 2 Steelmaking Shop at Chiba Works in order to ascertain the durability of the equipment. Slabs-in-coil were supplied to a finishing mill without reheating and hot rolling experiments were conducted.

### 4.1 Outline of Equipment

An outline of the industrial-scale KH caster is shown in **Fig. 4**. The mechanical specifications of the caster are given in **Table 2**, and the main specifications of the mold are shown in **Table 3**. The ladle capacity is 160 t. The mold is of a cassette construction which permits rapid changing of the entire mold. The belt is changed by separating the wide face from the two sides and installing (or removing) the belt, which is of welded loop construction, from the sides. The slab is either discharged in sheet form onto a table or wound by a coiler at high temperatures as slab-in-coil as it leaves the casting line.

To make possible the winding of multiple coils during an ongoing casting operation, a flying shear was installed between the caster and coiler, and a pusher was installed following the coiler. By winding the slab in coil form, heat dissipation is reduced because the exposed surface area decreases. This is advantageous for hot direct rolling and, at the same time, allows shortening of the casting line. To prevent heat radiation from the slab during casting, the table, flying shear, and coiler are equipped with heat retention covers.

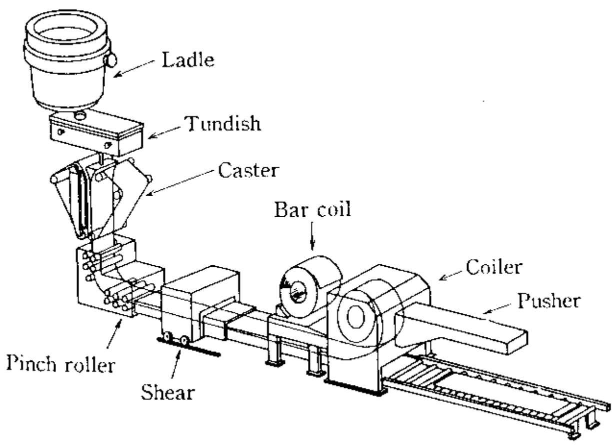

Fig. 4 Schematic drawing of KH caster

Table 2 Machine specifications of KH caster

| | |
|---|---|
| Ladle capacity | 160 t |
| Tundish capacity | 12 t |
| Casting floor | FL+6 300 mm |
| Level of pass line | FL− 200 mm |
| Mold length | 3.7 m |
| Casting speed | max. 15 m/min |
| Bending radius | 1.2 m |
| Shear | Flying shear |
| Coiler | |
| Inner dia. | 780 mm |
| Outer dia. | 2 350 mm |
| Coil weight | max. 20 t |

Table 3 Mold specifications of KH caster

| | |
|---|---|
| Mold size | |
| Thickness | 30 mm |
| Width | 700-1 300 mm (width change by hydrostatic cylinder) |
| Wide face | |
| Material | Steel belt with dried coating substance |
| Thickness | 1.2-1.6 mm |
| Width | 1 600 mm |
| Narrow face | |
| Material | Refractory plate |

A slab thickness of 30 mm was selected in consideration of ease of coiling, the material quality of rolled slab, the thickness accuracy of slabs and products, and the number of hot rolling stands available.

### 4.2 Method of Operation

Molten steel is poured from the tundish into the mold using an immersion nozzle. The same method of mold bath level control as in conventional continuous casting was adopted. The sliding nozzle opening of the tundish is controlled by monitoring the meniscus level, while the meniscus itself is sealed with argon. Since the wide faces of the mold move at the same speed as that at which the slab is withdrawn, the dummy bar is of simple construction, with a length of less than one meter. The dummy bar is driven by the moving belts which form the wide faces of the mold. The casting speed is 10 to 12.5 m/min maximum, and because the slab is completely solidified within the mold, no bulging whatsoever occurs. The belt is coated along its full length to reduce thermal loading; at the same time, this

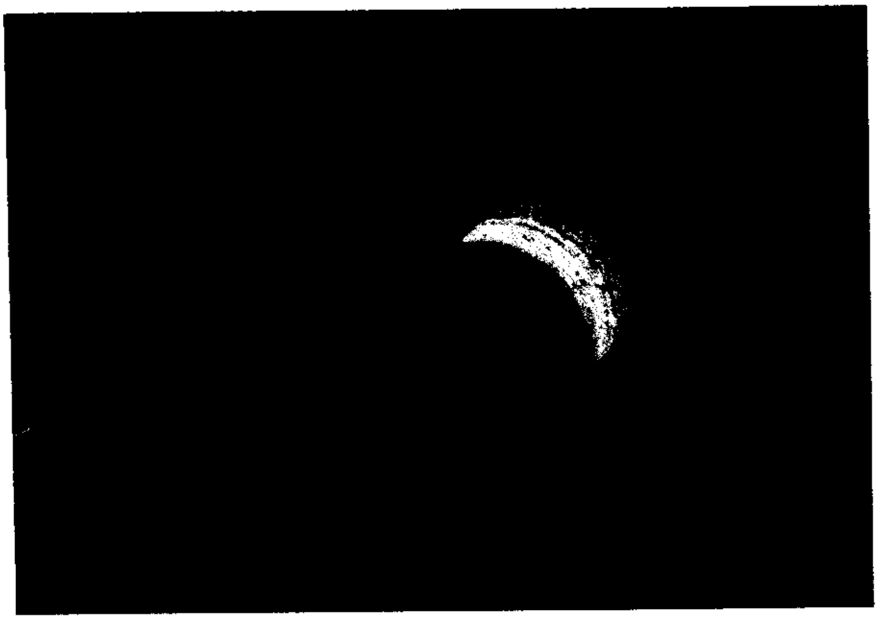

Photo 1 Appearance of thin slab coil just after coiling

construction contributes to better surface quality of the slab and higher slab delivery temperatures.

### 4.3 Results of Operation

About 140 experiments have been conducted since the startup of the KH caster in September 1987. Techniques for stable casting of 40- to 50-t slabs 800 mm and 1 000 mm in width (maximum casting length: about 230 m) have been established, and the following results obtained:

#### 4.3.1 Thermal deformation of belt

Because belt temperature increases are suppressed by the high-speed water film cooling system, virtually no thermal deformation of the belt occurs. It was ascertained that when an inorganic coating material is applied to the working face of the belt, the thermal load on the belt decreases and thermal deformation is prevented, giving the belt long-term durability in casting.

#### 4.3.2 Slab thickness distribution

The transverse slab thickness distribution is shown in **Fig. 5**. The broken line in the figure represents a case where the slab thickness is small in the middle of the slab width because the belt projected toward the slab owing to the loss of proper pressure balance when the water film pressure was higher than the ferrostatic pressure. In the figure, a uniform slab thickness is shown by the solid line. This uniform thickness was obtained by ensuring good balance between the water film pressure and the ferrostatic pressure, which was accomplished by modifying the diameters of the water inlets and outlets

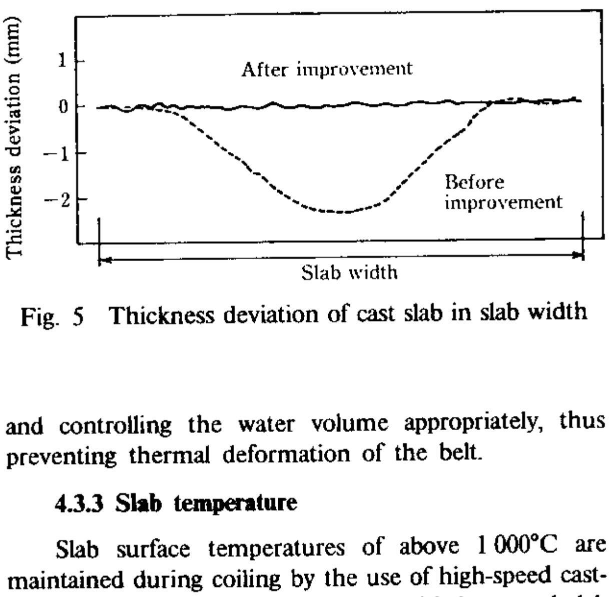


Fig. 5 Thickness deviation of cast slab in slab width

and controlling the water volume appropriately, thus preventing thermal deformation of the belt.

#### 4.3.3 Slab temperature

Slab surface temperatures of above 1 000°C are maintained during coiling by the use of high-speed casting and belt coating in conjunction with improved slab heat-retention equipment. As a result, rolling can be conducted at a temperature equivalent to that in conventional hot rolling without reheating of the slab-in-coil material. **Photo 1** shows the appearance of a slab-in-coil immediately after delivery from the line by the coil pusher.

## 5 Slab Quality and Quality of Hot-Direct-Rolled Products[36)]

### 5.1 Slab Surface Quality

The appearance of a slab-in-coil is shown in **Photo 2**.

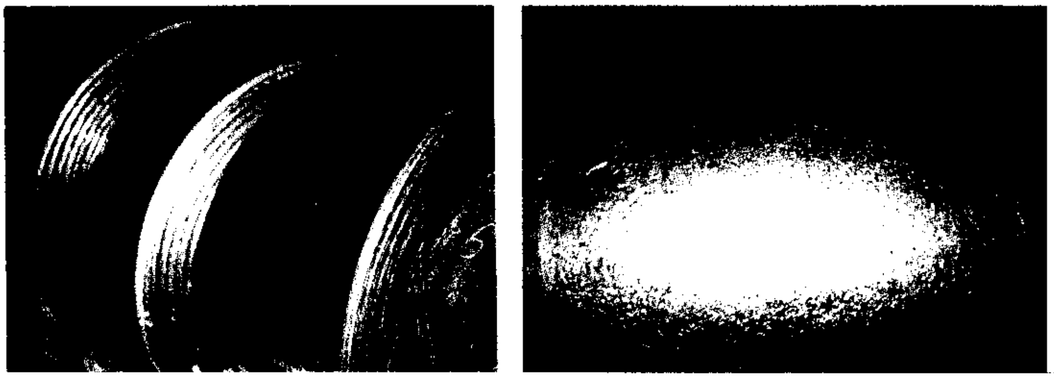

Photo 2 Appearance of thin slab coil

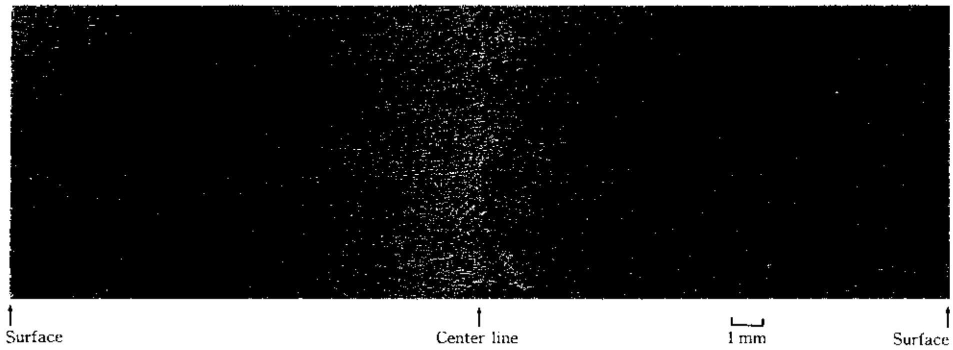


Photo 3 Solidification structure of thin slab (cross section, AISI 304)

This slab has a good surface free from the oscillation marks observed in conventional CC slabs because it was withdrawn from the caster at a speed equal to that of the belt movement. When the belt is not coated, the slab surface of steel grades characterized by large solidification shrinkage, such as medium-carbon steel, shows hexagonal irregularities, and such surface defects as longitudinal and transverse cracks frequently occur. When the belt is coated to achieve "soft cooling", irregularities of the slab surface decrease substantially, and major surface defects such as cracks is prevented.

### 5.2 Internal Quality of Slab

The solidification structure of a slab is shown in **Photo 3**. Since the slab is relatively thin, at 30 mm, the solidification structure is fine across the entire cross section, and a strongly oriented dendritic structure extends almost to the middle of the slab thickness. Abnormalities such as internal cracks are not observed.

Line analyses (beam diameter 50 $\mu$m, analysis width 0.5 mm) of phosphorus and manganese were made in the direction of the slab thickness using a microanalyzer. The results are shown in **Fig. 6**. Center segregation such as that observed in conventional CC slabs does not occur, because the solidification rate is high owing to the small slab thickness, because impurities are not entrained in the center of the enriched molten steel in the interstices of the dendrite owing to the nonoccurrence of bulging (bulging does not occur because the slab is supported over its entire surface), and because only a slight amount of molten steel is enriched prior to final solidification.

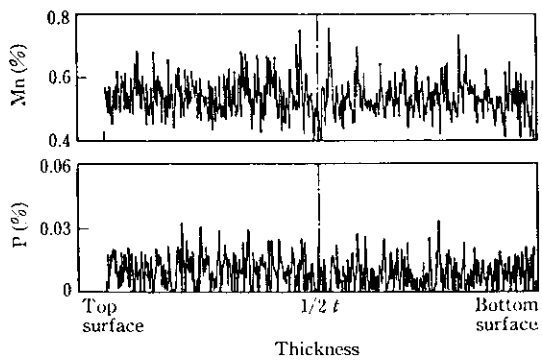


Fig. 6 Concentration distribution across slab thickness

The distribution of inclusions in the cross sections of slabs is shown in **Fig. 7**. An accumulation of inclusions near the top surface is observed in the slab cast by the horizontal type thin slab caster (KCC), while this phe-

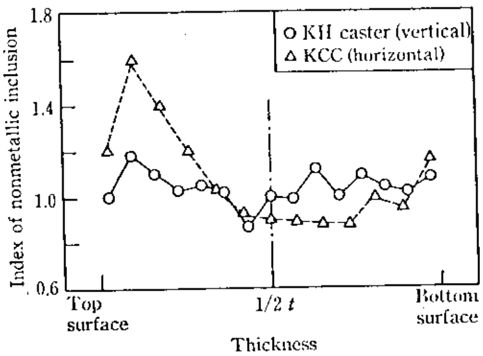


Fig. 7 Distribution of nonmetallic inclusion through slab thickness

nomenon does not occur in the KH caster because of its vertical configuration.

### 5.3 Results of Hot Direct Rolling without Reheating

A slab was cast under the conditions shown in **Table** 4 and wound using a coiler. The coil was put in an insulation box and transported by trailer to the No. 2 hot strip mill at Chiba Works, where it was put into the coil

Table 4 Casting conditions

| | |
|---|---|
| Steel grade | low carbon Al-killed |
| Casting speed | 10 m/min |
| Slab thickness | 30 mm |
| Coil weight | 12 t |

Table 5 Mechanical properties of hot-rolled coil (thickness 3.2 mm)

| | |
|---|---|
| Yield strength | 20.0 kgf/mm$^2$ |
| Yield elongation | 0.83% |
| Tensile strength | 32.8 kgf/mm$^2$ |
| Elongation | 44.6% |

box installed at the entry side of the finishing mill of the hot rolling mill. It was then uncoiled and rolled without reheating. This coil was reduced to a thickness of 3.2 mm in seven passes under almost the same conditions as those used with commercial products. The appearance of the coil after rolling, as shown in **Photo 4**, is similar to that of properly rolled commercial coils. As shown in **Table** 5, the mechanical properties of the experimental hot-rolled coil are virtually identical to those of conventional commercial products.

A slab of AISI 304 was cast under similar conditions (width: 1 000 mm) and an investigation was made into the effect of grinding of the slab surface on the surface properties of finished products. The slab was cooled, and one of its surfaces was ground, while the other was not. The slab was then reheated and finished by hot rolling. Annealing, pickling, and cold rolling were conducted as with commercial products, and a cold-rolled sheet 1 mm in thickness was obtained. The mechanical properties of this cold-rolled sheet were equivalent to those of commercial products, and surface properties such as luster and whiteness were good, even on unground surface.

Photo 4 Appearance of hot coil

## 6 Cooling Characteristics[37] of Slab with High-Speed Water Film Cooling System

### 6.1 Rate of Heat Flow in High-Speed Water Film Cooling System

The cooling characteristics of the slab depend on the steel grade, ferrostatic pressure, belt coating conditions, and other factors. The rate of heat flow from the slab in a stationary state is found by measuring $\theta_{w,out}$ and $\theta_{w,in}$ from Eq. (1), and the heat flux $q'$ betwween the belt and the cooling water is thus obtained.

$$q' = (\theta_{w,out} - \theta_{w,in}) Q C_W \rho_W / A \quad \cdots\cdots\cdots\cdots (1)$$

where $\theta_{w,out}$: Outlet temperature of cooling water
$\theta_{w,in}$: Inlet temperature of cooling water
$Q$: Flow rate of cooling water
$C_W$: Specific heat of cooling water
$\rho_W$: Specific weight of cooling water
$A$: Cooling area

The $q'$-values of a low-carbon steel (C < 0.08%) and a medium-carbon steel were found from Eq. (1) and are shown in **Fig. 8** for cases where the belt was coated and uncoated. This $q'$ tends to decrease as the slab moves from the upper to the lower part of the mold, then to increase and decrease again. This is attributed to the existence of two mutually contradictory effects in the solidification process: On one hand, thermal resistance increases due to the air gap between the solidified shell of the slab and the belt, while on the other hand, thermal resistance decreases because the contact between the solidified shell and the belt improves as the ferrostatic pressure increases.

As shown in **Fig. 8**, belt coating reduces the heat sink effect of the belt by about 30% and is effective in reducing the thermal load on the belt. A coated belt is also very effective from the standpoint of soft cooling.

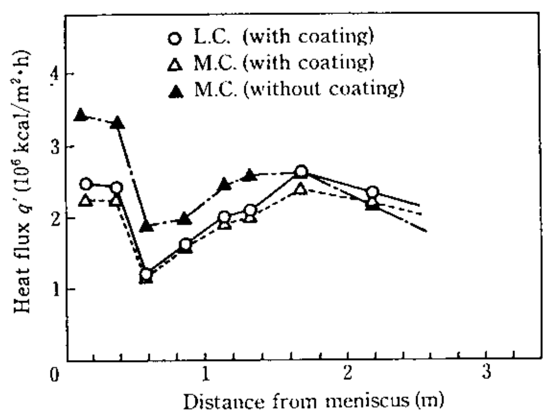


Fig. 8 Heat flux between belt and cooling water in the casting of low carbon and middle carbon steels

The rate of heat flow of a low-carbon steel is about 5% higher than that of a medium-carbon steel, presumably because the smoother slab surface of low-carbon steel is in better contact with the belt, resulting in lower heat transfer resistance.

### 6.2 Method of Calculation of Slab Cooling

The temperatures of the slab in the mold and of the belt are found by solving the following one-dimensional stationary heat transfer equation for the thickness direction of the slab:

$$\text{Within slab: } \rho_s C_s u \left(\frac{\partial \theta}{\partial z}\right) = \frac{\partial}{\partial x}\left(\lambda_s \frac{\partial \theta}{\partial x}\right) \quad \cdots\cdots\cdots\cdots (2)$$

$$\text{Within belt: } \rho_m C_m u \left(\frac{\partial \theta}{\partial z}\right) = \frac{\partial}{\partial x}\left(\lambda_m \frac{\partial \theta}{\partial x}\right) \quad \cdots\cdots\cdots\cdots (3)$$

$$\text{(Initial condition)} \quad z = 0 : 0 \leqq x \leqq 0.5 d_s \quad \theta = \theta_s^0$$
$$-d_m \leqq x \leqq 0 \quad \theta = \theta_m^0$$

$$\text{(Boundary condition)} \quad x = 0 \quad : q = -\lambda_s \left(\frac{\partial \theta}{\partial x}\right)$$
$$x = 0.5 d_s : \frac{\partial \theta}{\partial x} = 0$$
$$x = -d_m : q' = -\lambda_m \left(\frac{\partial \theta}{\partial x}\right)$$

where $\rho$: Density
$C$: Specific heat
$u$: Casting Speed
$\theta$: Temperature
$\lambda$: Thermal conductivity
$z$: Coordinate of slab casting direction
$x$: Coordinate of thickness direction of slab
$d$: Thickness
$q$: Heat flux between slab and belt
$q'$: Heat flux between belt and cooling water

The suffix s represents the slab (molten steel), and the suffix m the mold (belt).

For the slab, the specific heat $C_s$ and thermal conductivity $\lambda_s$ are used as functions of temperature. For the belt, however, because the temperature range is narrow, temperature calculations were made by a difference approximation of Eqs. (2) and (3) using constant values for specific heat $C_m$ and thermal conductivity $\lambda_m$.

The heat flux between the belt and cooling water, $q'$, is given by the following equation:

$$q' = \alpha_w \cdot (\theta'_m - \theta_w) \quad \cdots\cdots\cdots\cdots (4)$$

where $\alpha_w$: Coefficient of heat transfer between belt and cooling water
$\theta'_m$: Temperature of back side of belt (cooling water side)
$\theta_w$: Average cooling water temperature

It was ascertained that $\alpha_w$ in Eq. (4) is in good agreement with the results obtained from the equation for plane sheet cooling in the transition region (Colburn's equation). The following equation was used to express $\alpha_w$.

$$\alpha_w = 0.023 R_e^{0.8} P_r^{1/3} (\lambda_w / 2\delta) \quad \cdots\cdots\cdots\cdots\cdots (5)$$

where $R_e$: Reynolds number
$P_r$: Prandtl number
$\lambda_w$: Thermal conductivity of cooling water
$\delta$: Film thickness of cooling water

The heat flux between the slab and the belt is given by

$$q = \alpha_g \cdot (\theta_s - \theta_m) \quad \cdots\cdots\cdots\cdots\cdots\cdots (6)$$

where $\alpha_g$: Coefficient of heat transfer between slab and belt
$\theta_s$: Slab surface temperature
$\theta_m$: Belt surface temperature

In this equation, $\alpha_g$ is an unknown quantity. The value of $\alpha_g$ was determined by repeating calculations so that $q'$ calculated from Eqs. (3) and (4) using an assumed $\alpha_g$ would be in agreement with a value obtained from Eq. (1) using observed values.

### 6.3 Condition of Heat Transfer between Slab and Belt

The coefficient of heat transfer between the belt and the slab $\alpha_g$ was determined using the above-mentioned technique for a low-carbon steel and a medium-carbon steel when coated belts are used. In **Fig. 9**, the results are indicated by the solid line for a low-carbon steel and by the long-and-short dash line for a medium-carbon steel. In the same figure, the heat flux $q'$ between the belt and the cooling water calculated from this $q'$ is indicated by the broken lines. These calculated values are in close agreement with the observed values represented by the marks ○ and △. Thus the accuracy of the calculated heat transfer coefficient is high.

Changes in $\alpha_g$ in various parts of the mold reflect the above-mentioned thermal resistance between the slab and the mold; $\alpha_g$ is constant in the lower part of the mold where solidification is well advanced and the condition of contact between the slab and the belt is stable.

### 6.4 Results of Calculation of Slab Temperature

**Figure 10** shows calculated surface and center temperatures of a slab of low-carbon steel and measured slab surface temperatures. In the figure, the dotted line indicates the solidified shell thickness obtained from these calculations. The calculated values of slab surface temperature are in good agreement with the measured values, and the slab surface temperature is above 1 000°C after reheating. The solidification rate constant $k$ was calculated using the solidification completion time found from these calculations, and was found to be 24.4 mm/min$^{1/2}$. The $k$-value was calculated from the shell thickness determined from the sulfur print of a slab in which FeS was added to the molten steel in the mold during casting. The two values are in good agreement.

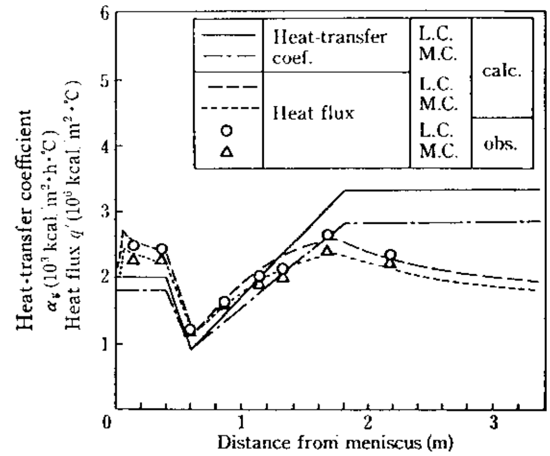


Fig. 9 Heat-transfer coefficient and heat flux between shell and belt in the casting of low carbon and middle carbon steels

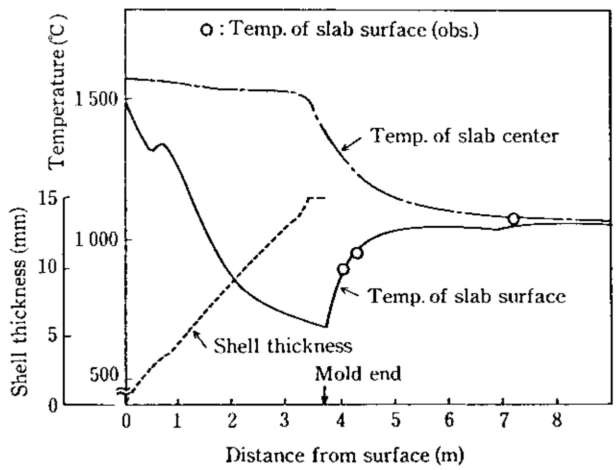


Fig. 10 Calculation results of slab temperature of low carbon steel (0.054%C, casting speed $V_R$ = 9 m/min)

## 7 Conclusions

In the development of a thin slab caster, small-scale experiments were first conducted on the scale of 200 kg and 5 000 kg of molten steel. Commercial-scale experiments were then conducted using a prototype twin belt type caster. This caster is characterized by a high-speed water film cooling system and a vertical type V-bell mouth mold. The following results were obtained:

(1) A technique for stably casting slabs 30 mm in thickness and 800 to 1 000 mm in width in quantities of 40 to 50 t/charge at casting speeds of 10 to 12.5 m/min maximum was established.

(2) Because the V-bell mouth mold pouring method was adopted, it was possible to use the conventional immersion nozzle and stably control the mold bath

level. Slabs of good surface quality were thus obtained.

(3) Because a high-speed water film cooling system was developed, uniform high performance total cooling is achieved, eliminating thermal deformation of the belt and making it possible to cast slabs with excellent thickness accuracy.

(4) Slabs are delivered at high temperature as a result of high-speed casting, belt coating, and improvement of the heat retention equipment, permitting hot direct rolling without reheating.

(5) The mechanical properties of the products of hot direct rolling were not significantly different from those of products manufactured by the conventional process.

Future research problems include the improvement of the durability of equipment components to an adequate level for long-term continuous operation under commercial conditions and the establishment of casting techniques for high-quality slabs suitable for high-grade cold-rolled steel sheets.

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