

# Development of High Quality Heavy Plates on Steelmaking Process at Kimitsu Works

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## Abstract

*Nippon Steel Corporation Kimitsu Works produces heavy plate steel for line-pipes in sour gas service and for offshore structure. As these are high-performance steels, Nippon Steel Corporation has developed advanced manufacturing technology, such as desulfurization, non-metallic-inclusion control, and inner defect free technology for slab. At Kimitsu Works, the No.6 continuous slab caster was put into operation in 2006. By optimizing the conditions of the soft reduction, center segregation and porosity has been drastically reduced and high productivity has been achieved. Along with desulfurization technology and oxide metallurgy Nippon Steel Corporation developed, we have established mass production technology of high quality heavy plate.*

## 1. Introduction

Nippon Steel Corporation Kimitsu Works is now producing high-quality steel plates and pipes for sour gas service, offshore marine structure, and the like that demand stringent material quality characteristics. Since these steel plates demand high quality not only for their heavy plate rolling mill process but also for their slab material; highly sophisticated technologies for the steelmaking process become crucial as well.

Lately, the demand for energy has been increasing along with the demand for high-quality steels; therefore, establishment of technologies that enable mass and stable production of such high-quality steels has become essentially important.

To comply with this demand, Kimitsu Works introduced No. 6 continuous casting machine in 2006 (hereafter referred to as “No. 6 CC”) to drastically enhance slab quality. No. 6 CC is equipped with a high reduction-force-bearing segment with high rigidity at the horizontal part, and by optimizing the casting condition with soft reduction, the compatible goal of reducing center segregation and center porosity with high productivity has been realized. Furthermore, by incorporating refining approaches such as lowering sulfur to an ultra-low level and oxide metallurgy, steelmaking technologies that enable mass production of high-quality heavy plates have been established.

This report describes the processes involved in the production of high-quality heavy plates at Kimitsu Works.

## 2. Quality Requirements of High-Quality Heavy Plates

### 2.1 Steel quality required for steelmaking

In the production of high-quality steels for line pipes in sour gas service and offshore marine structures, the following technologies are needed in the steel making process: 1. Desulfurizing technology to lower sulfur to an ultra-low level, 2. Shape control of nonmetallic inclusions (hereafter referred to as “inclusions,”) 3. Harmful inclusion eliminating technology, and 4. Center segregation and center-porosity eliminating technology.

### 2.2 Quality requirements of respective steel

#### 2.2.1 Steel plates for line pipes in sour gas service

For manufacturing steel plates for line pipes in sour gas service (Hereinafter referred to as “sour-gas-resistant steel plate,”) resistance to HIC (Hydrogen Induced Cracking) is the most important factor. As energy resource development has come to be applied in northern polar regions and sea beds, more stringent quality characteristics such as being HIC free, higher strength, higher toughness, and larger plate thickness (more than 30 mm) are required for material plates.

HIC is an internal crack developed not by stress caused by any external force but by the internal pressure of hydrogen acting as a source of stress, when under a sour condition ( $H_2S$ -rich surrounding), hydrogen is absorbed into and penetrates a steel plate and disperses inside and then arrested at the boundary surface of elongated MnS and nonmetallic inclusions like (Nb, Ti) (CN) in the steel plate.

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**Table 1** Chemical compositions of steel plate in sour gas service (mass%)

C	Si	Mn	P	S	Al	Others
0.04	0.25	1.44	≤ 0.010	≤ 0.001	0.020	Ni, Cr, Mo, Nb, Ti

**Table 2** Chemical compositions of steel plate for offshore structure (mass%)

C	Si	Mn	P	S	Al	Others
0.09	0.15	1.60	0.005	0.002	0.003	Ni, Cu, Nb, Ti

This crack propagates and expands along the finally solidified area in continuous casting, enriched with S, Mn, P, C, etc. (center segregation part).<sup>1-3)</sup> Therefore, to suppress the initiation and propagation of the cracks, high purification to the maximum extent possible, lowering of sulfur content to an ultra-low level in particular, and reduction of center segregation in continuous casting are necessary. Furthermore, coarse inclusions must be removed in the casting process as they can be the initiating points of HIC.

The typical aimed chemical composition of sour gas resistant steel plates is shown in **Table 1**. It consists of low contents of C and P, and a very low sulfur content of less than or equal to 10 ppm as the aimed upper criteria.

#### 2.2.2 Heavy plates for offshore marine construction

In recent years, along with a shift in energy resource development regions, application of heavy steel plates to offshore marine construction (hereafter referred to as “offshore plates”) is expanding to the deep sea bottom and ultra-low-temperature development sites such as those in the North Sea. For such heavy steel plates, the demand for their higher strength, larger plate thickness, ultra-low temperature toughness (excellent weld-joint characteristics at low temperatures), and so on has increased, and thus, enhancing steelmaking technologies has been for the focus.

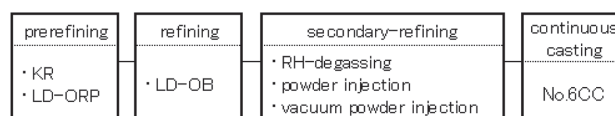
In continuous casting, porosity defects are caused at the center of a cast slab owing to the solidification and shrinkage of molten steel, wherein the porosity is suppressed by the utilization of soft reduction technology. However, the application of soft reduction technology becomes harder because the solidified shell strength increases as the strength of the steel material is increased. Furthermore, as the production of heavier plates having a thickness of 100 mm is increasing, crimping of center-porosity by rolling is becoming difficult; thus, countermeasures for the reduction of cast slab center porosity have also become very important.

Furthermore, to improve the ultra-low temperature toughness, it is necessary to fine ferrite grains at the heat-affected zone (HAZ) of a welded part. For this purpose, a technology that fines crystal grains at the HAZ by adjusting the composition of nonmetallic inclusions is applied. In steelmaking, it is required that the processing and casting of steel is performed in such a manner as to control the nonmetallic inclusion component to an aimed composition range and to disperse inclusions uniformly within a cast slab.<sup>4)</sup> On the other hand, coarse inclusions must be eliminated by all means as they can be the initiation points of various defects, which deteriorate quality.

Typical aimed chemical compositions of offshore plates are shown in **Table 2**. Steel is Ti-deoxidized to control the composition of nonmetallic inclusions and made aluminum free.

### 3. Production Process of High-Quality Heavy Plates

In **Fig. 1**, the manufacturing process of the No. 2 steelmaking plant at Kimitsu Works is shown. The manufacturing process of a

**Fig. 1** Manufacturing process of No.2 steelmaking plant at Kimitsu Works

sour-gas-resistant plate is characterized by the reduction of sulfur and phosphorous concentrations to the lowest possible level to obtain purity of the highest degree through desulfurization of molten iron by a Kanbara reactor (KR), dephosphorization by converter type pretreatment (LD-ORP), and by converter treatment (LD-OB: LD-Oxygen Bottom Blowing), followed by the secondary refining process of powder injection under a reduced ambient pressure (V-KIP) to lower sulfur content to the ultimate lowest possible level.

On the other hand, the manufacturing process of offshore plates by the converter treatment is same as that of sour-gas-resistant plates; however, RH and KIP desulfurization processes are employed in secondary refining. In these processes, control of inclusions (oxide metallurgy) is also conducted.

In the continuous casting process of No. 6 CC, both sour-gas-resistant plates and offshore plates are produced by taking advantage of the effect of in-tundish and in-mold molten steel flow control on the reduction of coarse inclusions and the effect of casting with soft reduction on the reduction of center segregation and center porosity.

### 4. Refining technologies for High-Quality Heavy Plates

#### 4.1 Desulfurization technology

Molten iron tapped off a blast furnace contains about  $30 \times 10^{-3}\%$  of sulfur (300 ppm). It is desulfurized to a low level of 3 ppm in the steelmaking process. Therefore, a desulfurizing ratio exceeding 99% is required. In the refining process for low-sulfur steel at Kimitsu Works, in order to attain this high desulfurizing ratio stably, desulfurization is applied at two stages: molten iron desulfurization before converter process (300→30 ppm) and molten steel desulfurization after converter blowing process (30→3-20 ppm).

##### 4.1.1 Molten iron desulfurization

At Kimitsu Works, desulfurizing and dephosphorizing simultaneously in a torpedo car, which is a container carrier between a blast furnace and a converter; however, to comply with the requirement of lowering the sulfur content to an extremely low level, KR process, which a molten iron ladle desulfurization method with high desulfurization performance, was introduced in 2000. KR is a process wherein a desulfurizing flux is cast while molten steel is being stirred and is exclusively used for desulfurization (reduction reaction), enabling a desulfurization of about 90% in a short period. Even if sulfur recovery in the converter process is taken into consideration, the process alone is capable of meeting the requirement of a sulfur content of about 50 ppm on products basis and has enabled the production of low-sulfur steel in a large quantity without difficulty.

##### 4.1.2 Molten-steel desulfurization

For steels with ultra-low sulfur content (upper criteria of standard: 30 ppm) unattainable by KR desulfurization method alone, desulfurization is applied in the secondary refining process. Either KIP or V-KIP is used depending on the required sulfur content.

KIP (**Fig. 2**) is a process in which a refractory-made lance is immersed in molten steel and a powder of the CaO system is injected with a carrier gas. Desulfurizing reaction is a direct reaction of the blown-in powder with the molten steel during flotation. Further, it is

a process with a strong stirring force and improves molten-steel cleanliness. The process is capable of securing a desulfurization ratio of about 60% and producing steel of a sulfur-content level of up to 20 ppm.

Furthermore, as 5 ppm of sulfur is aimed at for steels that require ultra-low sulfur content (e.g., steels for sour-gas-resistant plates), V-KIP with enhanced desulfurizing performance is used.<sup>5)</sup> V-KIP (Figs. 3, 4) is a process where powder is injected into molten steel in a ladle placed in a vacuum tank in the same way as in the case of KIP.

Owing to stirring under vacuum, the stirring force is drastically enhanced. Therefore, desulfurization efficiency is further improved and efficient desulfurization within a short period of time becomes

possible because of not only the desulfurizing effect of the powder of the CaO system during flotation but also the desulfurizing effect promoted by the contact and reaction with the top slag. The attainable sulfur content level is about 3 ppm. Furthermore, dehydrogenation is promoted simultaneously, thus shortening the refining time. Although the stirring force is strong, the melting-down damages in the ladle refractory and the like are large; the refractory melting-down damage is prevented by optimizing the slag composition with the addition of MgO and the like.<sup>6)</sup> Presently, a production of about 30,000 tons/month is possible.

**4.2 Oxide metallurgy**

Toughness at the HAZ at ultra-low temperatures is needed in steel plates for offshore marine construction. As  $\gamma$  grains grow coarse at the HAZ, ferrite grains also grow coarse, thus deteriorating the toughness. To prevent this, the toughness at the HAZ is improved by utilizing the nonmetallic inclusions formed during steel-making. In TiO steels, since inclusion composition is made to be TiO based, conventional Al deoxidation can not be applied. As lamellar tear resistance characteristics are required for an offshore plate, although it is a low-sulfur steel, Ti deoxidation raises the oxygen content in steel and deteriorates the desulfurizing reaction. To this effect, by applying an oxygen-control technology in the refining process, complete elimination of aluminum and lowering of sulfur content is compatibly realized.

Furthermore, in HTUFF steel (Super High HAZ Toughness Technology with Fine Microstructure imparted by Fine Particles), where low-temperature toughness is further enhanced,<sup>7)</sup> the composition of inclusions is controlled by adding magnesium. Nonmetallic, nano-size inclusions stable at a temperature as high as 1,400 °C are finely dispersed in a cast slab, which suppresses the growth of  $\gamma$  grains.

**5. Continuous Casting of High-Quality Heavy Plates**

**5.1 Features of No. 6 CC and its equipment specification**

Nippon Steel Corporation built No. 6 CC at Kimitsu Works in 2006 to enhance the quality of heavy plates and pipes. Fig. 5 shows the cross section of No. 6 CC, and Table 3 shows the basic design features. No. 6 CC is a one-strand vertical-bending type continuous casting machine with a metallurgical length of 41.2 m. One strand type was selected in view of the balance between the supply pitch on the refining-process side and continuous casting productivity, as well as the reduction of bottom and top scrap. Furthermore, cast slab thickness was selected to be same as with the slab thickness from No. 2 Continuous Casting Machine, a main continuous casting machine, then already under operation, for supplying slabs for heavy plates (Hereinafter referred to as “No. 2 CC”). Therefore, there are two thicknesses, 240 and 300 mm. As for the equipment capability for quality, No. 6 CC was designed on the basis of the capability of

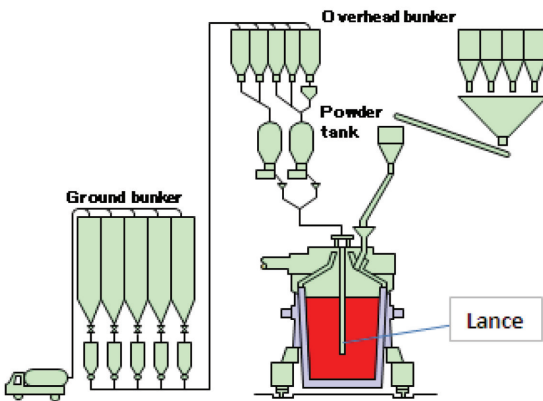


Fig. 2 Schematic diagram of the KIP apparatus

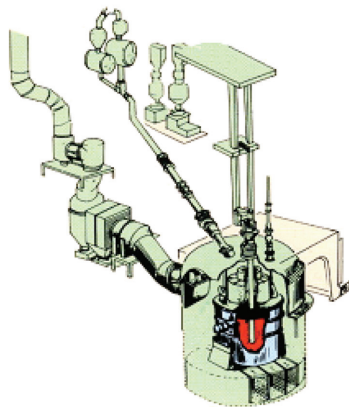


Fig. 3 Schematic diagram of the V-KIP apparatus

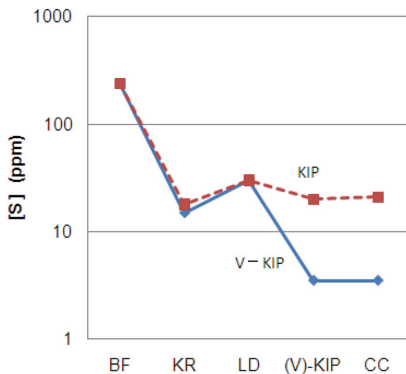


Fig. 4 Trend of desulfurization process at Kimitsu Works

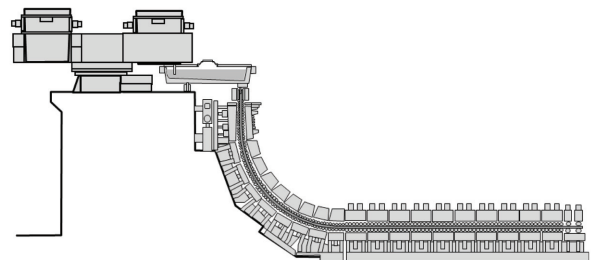


Fig. 5 Cross section of No.6 CC

Table 3 Basic design features of No.6 CC

Metallurgical length		41.2 m
Number of strand		1
Machine type		Vertical-bending
Size of slab	Thickness	240, 300 mm
	Width	980 - 2,300 mm
	Length	5,200 - 12,800 mm
Exchanging method of casting thickness		Exchanging narrow face of mould
Content of tundish		60 ton

No. 2 CC equipment with the addition of capability strength.

## 5.2 Technology for reducing large-size inclusions

When molten steel including nonmetallic inclusions is continuously cast, the nonmetallic inclusions remain in the cast slabs and cause internal defects, surface defects, etc. Therefore, a technology for reducing large inclusions is very essential for casting high-quality slabs, and measures for reducing inclusions in a tundish and a mold have been employed since the past.

### 5.2.1 Technology for controlling molten-steel flow in a tundish

The measures for reducing inclusions in a tundish include securing inclusion-flotation time by enlarging the tundish capacity<sup>8,9)</sup> and optimizing molten steel flow control by optimizing dam arrangement in a tundish.<sup>10,11)</sup>

In No. 6 CC, when compared with No. 2 CC, flotation of inclusions is further promoted by increasing the molten steel flowing distance in the tundish and by optimizing the dam arrangement in the tundish. Fig. 6 shows the cross section of the tundish and dam arrangement in the tundish in No. 6 CC. No. 2 CC is of the two-strand type and is equipped with a boat-type tundish having a capacity of 60 or 30 ton capacity per strand. On the other hand, No.6 CC is of one strand type and, with installation of a tundish of the same boat-type design and with same tundish capacity of 60 tons as with No. 2 CC, molten steel flowing distance twice longer is secured.

Further, in No. 6 CC, an upper dam and a lower dam followed by another upper dam are arranged in order in the direction from the ladle to the immersion nozzle. The first upper dam makes large inclusions and slag flowing from the ladle surface and retains them at the surface of molten steel in the tundish, blocking and not allowing them flow toward the mold. The molten steel that flows underneath the first upper dam collides with the lower dam, thus the lower dam prevents the molten steel from flowing directly into the immersion nozzle located downstream, at the same time forming an upward flow acting as if pushing the inclusion-bearing molten steel upward toward the molten-steel surface in the tundish. Then, the second upper dam forms a downward flow right in front of itself and promotes inclusion flotation by thermal convection afterward. Fig. 7 shows the result of the numerical analysis of this behavior in a tundish. It has been confirmed that adoption of this dam arrangement effectively promotes inclusion flotation on the molten-steel surface in a tundish for more effective removal of inclusions.

The temperature of molten steel in a tundish is also an important factor for levitation separation of inclusions. To avoid the adverse effect of low temperature, which retards inclusion levitation, it is desired that the molten-steel temperature is controlled to and maintained within a certain constant range. However, in an actual casting, the molten-steel temperature in a tundish varies widely owing to varied temperatures after refining and a drop in the molten-steel

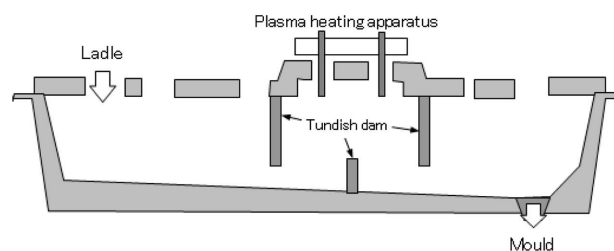


Fig. 6 Cross section of the tundish at No.6CC

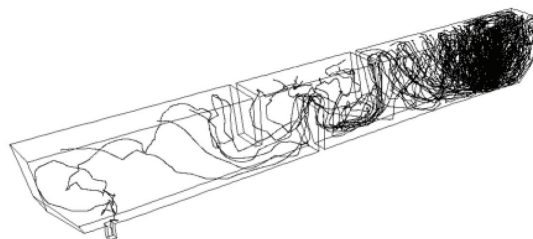


Fig. 7 Behavior of inclusions in the tundish by numerical analysis

temperature in the ladle with the passage of time. To cope with such temperature variations, a molten steel heating device is equipped to compensate molten steel temperature drop in a tundish.<sup>12)</sup>

In No. 6 CC as well, a plasma-type heating device is used to ensure the desired molten-steel temperature. (Fig. 6) The plasma heating device is installed at the center of the tundish in its longitudinal direction, and the molten steel is heated in a heating space formed by the two upper dams and tundish walls. By applying plasma heating, temperature variations throughout the entire casting are suppressed, and the temperature drop during ladle exchange is also compensated for. In particular, with the employment of an automatic controlling function to control the distance between the plasma torches and the molten-steel surface, plasma heating is possible even when the molten steel is at a very low level in a tundish at the time of ladle exchange.

### 5.2.2 In-mold molten steel flow control technology

For the removal of large inclusions that penetrate a mold, in-mold molten steel flow control is important. As for flow control, overall optimization of the in-mold electromagnetic stirring equipment (hereafter referred to as "M-EMS"),<sup>13,14)</sup> electromagnetic brake, molten steel level control, prevention of blocking of a teeming system like immersion nozzle, and so on is important.

In No. 6 CC, for in-mold molten steel flow control, the M-EMS is equipped in the same way as that in No. 2 CC. By imparting stable molten-steel flow to right below the solidified shell face with M-EMS, it is possible to remove inclusions larger than 100  $\mu\text{m}$ .<sup>15)</sup> This is attributed to the fact that the inclusion-discharging force of the solidified shell is intensified by a cleansing effect produced by the pressure inclination developed by the increased molten-steel-flow velocity right below the solidified shell face. Fig. 8 shows the result of numerical analysis of in-mold molten-steel flow when M-EMS is applied. Beneath the immersed nozzle located at the center of a mold in its width direction, upward flow (environmental flow) is developed by the stirring flow produced by M-EMS. Inclusions and blowholes that penetrate the mold are brought to the surface by this upward flow, and thus, a suppressing effect is expected for further penetration of inclusions and blowholes into the areas of a cast slab, where they are already concentrated.



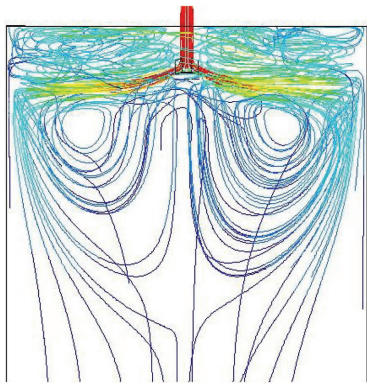


Fig. 8 Levitation of molten steel with M-EMS in mould by numerical analysis

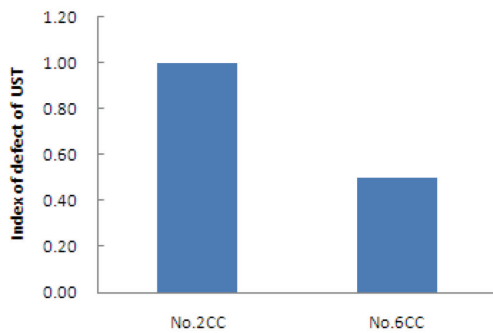


Fig. 9 Results of defect of inclusion at steel plates

5.2.3 Improving effects

Fig. 9 shows rates of occurrence of defects caused by inclusions in steel plates before and after the commissioning of No. 6 CC. With the commissioning of No. 6 CC, the rate of occurrence of defects caused by inclusions has decreased, and a stable quality level is secured.

5.3 Technologies for reducing center segregation and center-porosity

5.3.1 Soft reduction technology

Cast slab soft reduction technology<sup>16)</sup> that suppresses the molten-steel flow at the solidification terminating stage is employed as a technology to reduce the size of center segregation particles. Center segregation is caused by the occurrence of flow of condensed molten steel at the final stage of solidification, which is caused by phenomena such as shrinking at solidification, thermal shrinking, and inter-roll bulging.

The cast slab soft reduction method is a technology that suppresses the molten-steel flow caused by solidification shrinkage by reducing the roll gap by an amount equivalent to the amount of the shrinkage, namely offsetting the solidification shrinkage with roll-gap reduction at the final solidification stage in continuous casting. The technology can be utilized most effectively by decreasing the roll diameter and roll pitch in a casting machine, together with the selection of optimum roll reduction amount meeting the casting condition such as cast slab thickness and casting speed.<sup>17-19)</sup> In No. 6 CC, for the entire horizontal length of 20 m, rolls are arranged at short intervals and are grouped into high-rigid segments. In No. 6 CC, roll separation is shortened to three quarters and segment deflection to one quarter when compared with No. 2 CC (result of calculation of mechanical structure).

5.3.2 Reduction of center segregation

Fig. 10 shows results of center segregation in No. 2 CC examined with etch printing.<sup>20)</sup> In No. 6 CC, it is observed that the center-segregated particles are small and center segregation is considerably reduced. Furthermore, in Fig. 11, evaluation results of indexes of manganese segregation in No. 6 CC and No. 2 CC are shown. Manganese-concentration distribution at the center segregation was analyzed by an X-ray micro analyzer (Computer Aided Micro Analyzer),<sup>21)</sup> and the index of segregation of manganese was evaluated. The index is reduced to three quarters compared with No. 2 CC.

Fig. 12 shows the typical manganese-concentration distributions in No. 6 CC and No. 2 CC. Generally, as observed in the case of No. 2 CC, negative segregation is observed around the positive segregation at the center in the thickness direction. On the other hand, cen-

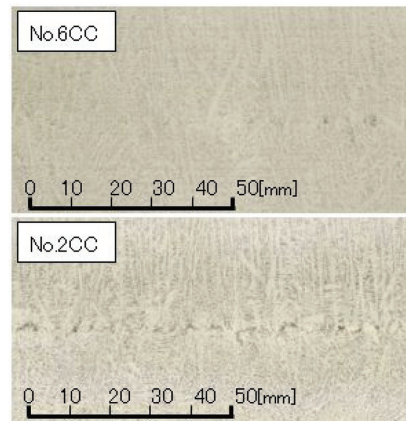


Fig. 10 Results of center segregation by method of etch printing method

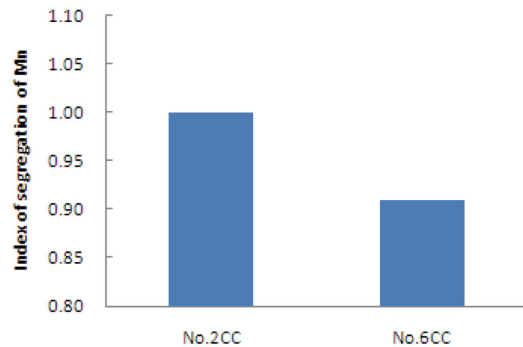


Fig. 11 Results of center segregation of manganese

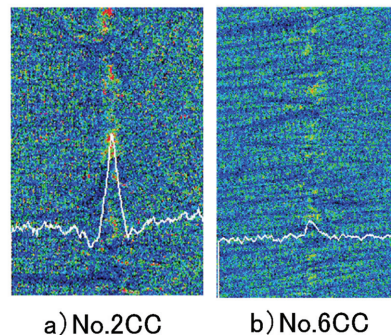


Fig. 12 Results of concentration distribution of manganese

ter-segregation distribution in the case of No. 6 CC is characterized by less amount of negative segregation around the positive segregation. Two-dimensional numerical analysis showed that on the assumption that a bulging exists between rolls, repetition of compression and expansion at the massy zone develops flow from the peripheral zone to the center, and thus, a concentration profile is produced with a negative segregation band around positive segregation.<sup>22)</sup> It is considered that in No. 6 CC, since the influence of bulging was minimized by the adoption of a short-roll pitch and enhanced segment rigidity, a center-segregation band with a smaller negative-segregation band was formed.

#### 5.3.3 Reduction of center porosity

Fig. 13 shows the center-porosity density. The number of porosities that are greater than 1 mm, detected with ultra-supersonic-tester, was evaluated. The density of porosity in No. 6 CC has been drastically reduced to one tenth of the level of No. 2 CC.

#### 5.4 Effect of improvement in cast slab quality on product material

Accompanied by the improvement in cast-slab quality by the introduction of No. 6 CC and optimization of operation technology, the characteristics of the material of product plates have also been improved. Fig. 14 shows the toughness values at  $1/2t$  ( $t$ : plate thickness) of product plates.

Owing to the improvement of center segregation of the cast slab, the toughness value at  $1/2t$  was improved by about 20%. With the effect of improvement of segregation, production of plates with higher strength and larger thickness has been made possible. As for offshore plates, Nippon Steel Corporation is responding to customers' needs that have emerged in coping with the trend of their projects, which are growing bigger in scale, and is pushing forward the production of plates with higher strength and larger thickness by taking advantage of the refining technology, rolling technology at

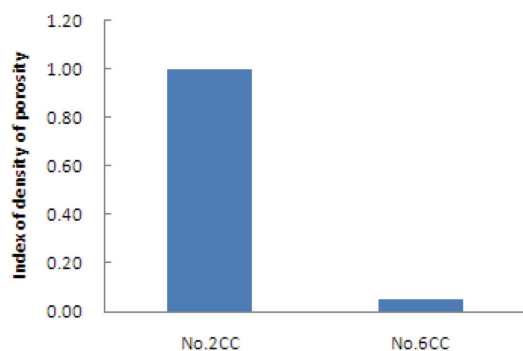


Fig. 13 Results of Center-porosity density

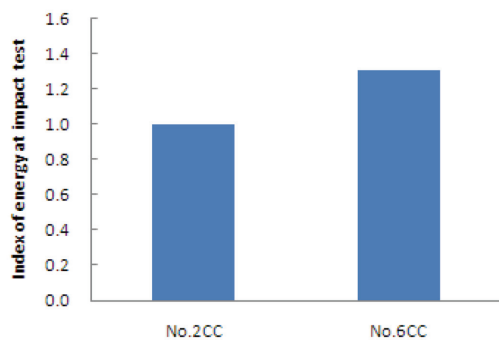


Fig. 14 Results of Charpy impact test at  $1/2t$  of steel plates

plate-rolling mill, and the abovementioned effect of reducing segregation.

## 6. Highly Efficient Operation Technology for High-Quality Heavy Plates

To cope with the increasing need for high-quality heavy plates, establishment of an efficient mass-production system for high-quality heavy plates in steelmaking is essential. Particularly, in order to cope with the increase in cast slab surface defects as a result of increased strength (addition of more alloying metals) and enlarged plate thickness, it is essential to utilize equipment capability for the quality improvement of No. 6 CC to the highest possible extent.

### 6.1 Enhancement of conditioning-free slab ratio by reduction of surface defects

Surface defects in a cast slab, which occur during the continuous casting process, need conditioning with a grinder and/or by scarfing for removal after casting. Therefore, direct feeding of slabs in a hot sate to a plate-rolling mill is hampered. The main defects in a cast slab that necessitate conditioning include longitudinal cracks, transverse cracks at a corner, and the like. To eliminate conditioning for these, suppression of surface defects by utilizing the in-mold molten steel flow control technology and secondary cooling control technology is necessary.

#### 6.1.1 Suppression of longitudinal cracks

Longitudinal cracks are caused by the strain exerted by a shell, which is in turn caused by uneven solidified shell thickness in width direction developed in the early stage of solidification.<sup>23)</sup> This unevenness in the solidified shell thickness is considered to be attributed to the uneven growth of the shell caused by the uneven removal of heat in the width direction, molten steel stagnating more at the meniscus, and uneven temperature distribution of molten steel in the width direction of a slab. Particularly, in medium-carbon steels like offshore plates, longitudinal cracks are more likely to be caused by this uneven cooling. Therefore, it is important to suppress the longitudinal cracks by preventing solidification unevenness with the even removal of heat from the mold by optimizing powder composition and evenness of the molten steel temperature distribution by applying M-EMS.<sup>15)</sup> In No. 6 CC, longitudinal cracks are suppressed by optimizing the M-EMS operating condition and selection of optimum powder.

#### 6.1.2 Suppression of transverse cracks in corners

Transverse cracks in the corners of a slab cast by a vertical-bending type continuous casting machine tend to be developed at the bending and straightening points of a machine, where the cast-slab surface is acted upon by a tensile force. Transverse cracks are developed by embrittlement in the third region, a phenomenon specific to steel. Therefore, cast-steel temperature must be controlled to avoid embrittling when the steel travels through the bending and straightening points.<sup>24)</sup> Many of the transverse cracks occur in the corner sections of a cast slab, where cooling is promoted. Therefore, one of the countermeasures is the application of slower secondary cooling to corners and their neighborhood than the secondary cooling at slab center.

However, excessive slow cooling in a corner section causes delay in cooling near the corner and thus deteriorates the center segregation and center porosity. Then, in No. 6 CC, the secondary cooling system is so established that the secondary spray cooling piping system is split into two sections widthwise, a main line piping for cooling center section and another line piping for cooling cast steel corner section, and the flow rate of the respective line so split is inde-

pendently controlled. By optimizing the flow rate of a respective line depending on the characteristics of steel and by controlling the crater-end shape, cast slab corner transverse cracks are suppressed while variations in center segregation and center porosity in the width direction of the cast slab are reduced as well.

#### 6.1.3 Improvement of conditioning-free slab ratio

By optimizing these continuous casting technologies, needs for cast slab conditioning have decreased to a great extent, and thereby, direct feeding to a plate-rolling plant has become possible. Currently, 99% of the slabs for a plate mill are rolled without conditioning.

### 6.2 Improvement of casting-time ratio

#### 6.2.1 Increasing the number of heats per sequence

By increasing the number of heats per sequence in continuous-continuous casting, the following merits are obtained; increasing the casting yield by reducing the amount of bottom and top ends discarded as scrap and increasing the operating ratio by reducing the numbers of starting of casting and decreasing the casting speed at the termination of casting. In No. 6 CC, the number of heats of continuous-continuous casting is restricted by the melt-down damage of the refractory of the immersion nozzle on the in-mold molten-steel surface. By application of a powder that suppresses the refractory melting-down damage and by optimizing the shape of an immersion nozzle, the number of heats per sequence in continuous-continuous casting has been increased.

#### 6.2.2 Decreasing the time for casting thickness change

There are two cast slab thicknesses in No. 6 CC, 240 and 300 mm, made same as with the ones in No. 2 CC in view of rolling productivity and integrated yield in a heavy-plate mill. The casting of a slab having a thickness of 300 mm in No. 2 CC was confined to a chance either before or after scheduled maintenance to avoid deterioration of the operating ratio owing to time loss in mold changing for thickness change (loss of 4 hours/change × 2). In No. 6 CC, in order to cast slabs of having a thickness of 300 mm without lowering the productivity of steelmaking and without any limitation imposed on the casting schedule, a quick narrow side mold exchange

system is employed. With this system, the designing of production schedule with priority placed on plate mill rolling conditions has become possible. In No. 2 CC, share of slabs having a thickness of 300 mm in casting was only about 3%, which has been enhanced to as high as about 50% in No. 6 CC.

## 7. Conclusion

Kimitsu Works has strengthened its technical capability for the mass-production of high-quality heavy plates for line pipes in sour gas service and for offshore marine construction by utilizing the desulfurizing technology to obtain ultra-low sulfur levels and oxide metallurgy in refining and center segregation and center-porosity-reduction technology in continuous casting.

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