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Development of Revolutionary Continuous Castings Technology for Thick Plates at Kashima Works

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Abstract

Kashima Works manufactured high-grade steel plates such as steel for large heat input welding, high-tensile steel, and 9% Ni steel. In some steel grades, transverse cracks occur on the surface of the slab, which demand extra processes such as a slab inspection and grinding, and cause yield loss. Moreover, the center porosity of the slab becomes a problem in plates that require high slab inner quality, such as a plate whose product thickness exceeds 100 mm. To overcome these problems, Surface Structure Control cooling (SSC) and Porosity Control of Casting Slab (PCCS) technologies were developed and adopted in No. 2 CC. It was also made possible to cast 9% Ni steel, which is austenite single phase and also crack sensitive. As a result, the manufacture of high-grade steel plates under high productivity has been enabled.

1. Introduction

At Kashima Works, slabs for high-grade steel plates are manufactured with high productivity. Quality requirements continue to grow more stringent as the surrounding conditions of steel material usage tighten. Therefore, the suppression of defects in the casting process as well as reduction of impurities in the refining process are becoming a strong concern. Particularly, in the low alloy steels added with Nb, V, Ni, Cu, and so forth, surface cracks tend to occur on the cast slab surface, and additional processes such as slab inspection, conditioning, and suppression of the deterioration of yield become a serious issue. Then, the Surface Structure Control cooling (SSC) method was developed.[1] The method prevents the occurrence of transverse cracks by cooling steel once rapidly immediately below the mold to below the γ to α transformation temperature and by the heat recovery.

Meanwhile, extra thick steel plates that exceed 100 mm in thickness are being used for bridges, dies, large industrial machines and so forth, and require high quality and soundness of internal quality. In manufacturing such extra thick steel plates, it is important to secure the internal quality. In order to secure the mechanical properties of their thickness center part and to pressure-weld the center porosity (voids) of a cast slab, heavy reduction is applied in rolling. However, in the conventional process of rolling of conventional slabs cast by a regular continuous casting machine, due to the restriction of the rolling mill capacity, slight porosity defects remain even under the heavy reduction and are identified as defective by high-sensitivity ultrasonic testing. Therefore, the thickness of the producible steel plate is limited.

To solve this problem of collapsing the porosity, we have developed a method of reducing the cast slab center porosity that develops problematic internal quality by applying heavy reduction to the cast slab at its final solidification stage in a continuous casting machine (PCCS method: Porosity Control of Casting Slab) (**Fig. 1**).[2] Furthermore, use of 9% Ni steel for the storage tank of liquefied natural gas under a very low temperature was also studied. Namely, although the steel solidifies under the γ single phase and surface cracks caused by the γ grain boundary cracks appear, the production of the steel by continuous casting was realized by optimizing the secondary cooling condition.

As a result, the production of the extra thick steel plates was realized through casting by a vertical-bending type continuous casting machine and steel plate production process. In this article, the frameworks of these technologies are described.

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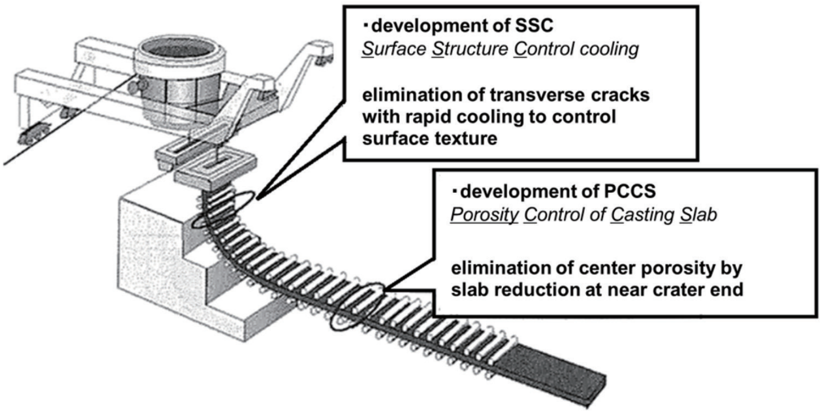

Fig. 1 Application of new casting technology, No. 2 CC, Kashima Works

2. Suppression of Surface Crack by Rapid Cooling Immediately Below Mold and Heat Recovery Method (SSC)

2.1 Framework of control of cast slab surface layer microstructure

Direct rolling in which cast slabs are directly transferred from the continuous casting process to the rolling process without cooling the cast slab to room temperature is positively promoted since the direct rolling contributes to the rationalization of the production process and reduction of cost. Therefore, it is necessary to completely suppress the surface defects at the cast slab stage. On the other hand, along with the recent further sophistication of the required characteristics of materials, the production of low alloy steel with the addition of such elements as Nb, V, Ni, Cu, and so forth is increasing. These steels sometimes become sensitive to transverse cracks.

Regarding transverse cracks, a number of researches have been conducted and it has been clarified that transverse cracks are attributed to the high temperature embrittlement in the neighborhood of the γ to α transformation temperature and caused by the unbending of the cast slab in this temperature region.[3–5]. Therefore, in the actual continuous casting operation, the surface temperature of the cast slab at the time of unbending is generally controlled to be either above or below the brittle temperature range to prevent unbending in the said temperature region.

Herein, by controlling the microstructure of the cast slab surface layer (SSC) by utilizing the secondary cooling of the continuous casting machine and preventing thereby the film-like ferrite precipitation along grain boundaries that triggers crack, and by developing a method to fully eliminate the embrittlement mechanism, eradication of cracks was promoted. As a result, at the No. 2 continuous casting machine at Kashima Works that produces slabs for plate mill (hereinafter referred to as 2CC), a technology that suppresses the slab surface transverse cracks by the secondary cooling in the said 2CC was established.

Figure 2 shows an example of the microstructure of the cast slab surface layer obtained when the microstructure control method was applied to the continuous casting of the crack-sensitive Nb, Ni, and Ti bearing slabs for plate mill. The slab surface layer microstructure of several mm in depth without film-like ferrite that precipitated along the grain boundaries is obtained along the entire width and length of a cast slab. Since the transverse cracks occur when the bending and unbending stress is concentrated onto the film-like ferrite at the boundaries, suppression of the cracks by the microstructure control in this manner becomes possible.

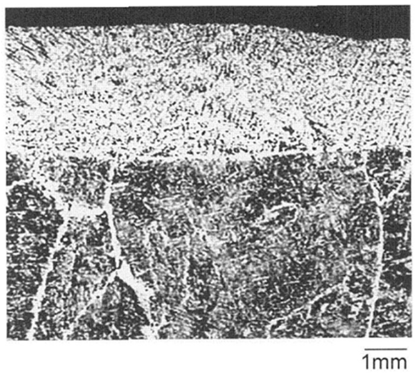

Fig. 2 Microstructure of slab surface, with SSC

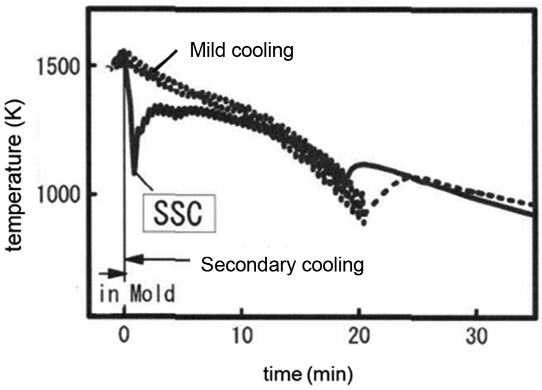

Fig. 3 Temperature history of SSC and conventional mild cooling

In **Fig. 3**, the temperature history to realize this controlled cast slab surface layer microstructure is presented. This figure shows the temperature transition at the point 5 mm below the surface of a 200 kg cast piece when it was cast in a static manner, stripped out of the mold, and mist-cooled immediately thereafter. The cast piece surface layer microstructures obtained in the following cases were compared: mild cooling wherein the cast piece is mildly cooled after stripping out and mildly cooled simulating the actual continuous casting operation, and once rapidly cooled immediately after stripping out and mildly cooled after the temperature is recovered up to 1 300 K (SSC). Tests were conducted by varying the lowest temperature and the cooling rate when rapid-cooling is applied and the ef-

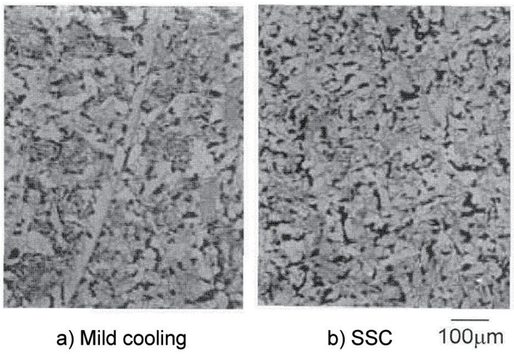

Fig. 4 Microstructure of slab surface layer in 200 kg ingot cooling test

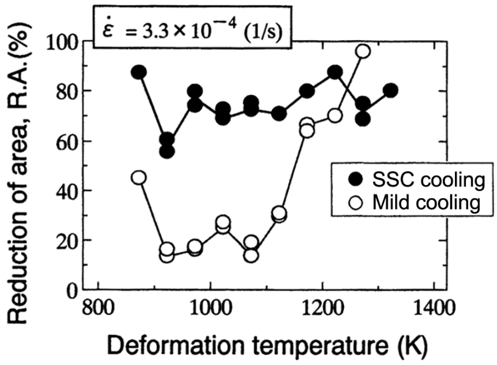

Fig. 5 Effect of temperature history on hot ductility

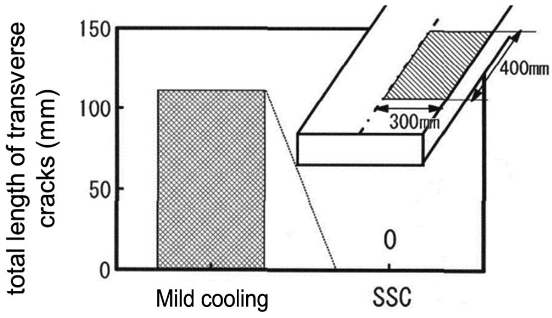

Fig. 6 Status of transverse cracking during slab bending test

fect thereof on microstructure was investigated.

The microstructures in the neighborhood of the temperature measuring point obtained under the two cases are shown in **Fig. 4**. In the mild cooling, similarly to the actually continuously-cast slabs, the film-like ferrite is formed along the γ grain boundaries in a large number. On the other hand, it was clarified that by employing SSC wherein rapid-cooling is once applied and recovering heat thereafter, the growth of the ferrite can be suppressed.[6] Furthermore, the γ grain sizes of the surface layers of the slab cast in the different conditions were compared and there was no difference between that of the mild cooling and that of SSC.

2.2 Hot ductility improvement effect of SSC

Hot ductility was investigated by using a liquefied state and solidified state test specimen and the effect of SSC on hot ductility was confirmed. A tensile testing machine was fabricated equipped with a cold crucible type induction heating apparatus to hold the test specimen in the state of liquid and the hot ductility was evaluated under the reproduced as-cast state microstructure.[7]

Figure 5 shows the result of the investigation of the hot ductility (R.A.: Reduction of Area) of the mild-cooled cast slab and the SSC-cooled cast slab of an identical Nb, Ni, and Ti added steel. R.A varies greatly depending on the temperature transition and it was found that by SSC, high R.A. is obtained even in the brittle temperature range and embrittlement itself is eliminated. The microstructure in the neighborhood of the fracture surface of the test specimen and that of the test specimen applied with the prescribed temperature transition but not tension-tested were investigated. No formation of the film-like ferrite along the grain boundaries was observed. In addition, there was no difference in the γ grain size between that of the mild-cooled cast test specimen and that of the SSC-cooled cast.

Hot ductility of a test specimen applied with simulated SSC of rapid cooling and heat recovery but without melting and solidifying was also compared and unlike the result of Fig. 5, the brittle temperature range was observed. Namely, it was also clarified that to evaluate the hot ductility of an as-cast slab, implementation of the tensile strength test of a test specimen developed from the liquefied state through to the solidified state is essential.

2.3 Cast slab surface crack suppression effect

To confirm the effect of SSC on the suppression of cracks, bending strain was rendered to a cast slab continuously cast by a laboratory continuous casting machine and the status of transverse cracking was investigated.[6] A cast slab of 150 mm × 600 mm in section and 4 meters in length was cast from 2.5 ton molten steel by a vertical type laboratory continuous casting machine and after casting, by the bending rolls installed below the casting machine, the cast slab was applied with a bending strain equivalent to that of a 10 mR bending radius of an actual continuous casting machine at the strain rate of 2×10^{-4} 1/s. Radiation thermometers were installed for the strand of the continuous casting machine and at the bending test section, and it was confirmed that the prescribed temperature transition was satisfied.

Figure 6 shows the total length of the transverse cracks that occurred in the region of 300 mm × 400 mm of the part that was bent for test purposes at a cast slab surface temperature of 1 170 K. In the mild cooling, cracks occurred along the grain boundaries and the transverse cracks were reproduced on a laboratory basis. Meanwhile, in SSC, cracks were not observed despite the same bending strain being applied to the cast slab at the same temperature. The investigation on the microstructure of the cast slab surface layer revealed that the film-like ferrite was formed in the mild cooling, while in SSC, no such formation occurred. Accordingly, the effect of the control of the microstructure of the cast slab surface layer on the suppression of cracks was confirmed.

2.4 Mechanism that differentiates cast slab surface layer microstructure

Since no difference in the γ grain size between that of mild cooling and that of SSC was observed, the microstructure change due to SSC is not caused by the refinement of the γ grain caused by $\gamma \rightarrow \alpha \rightarrow \gamma$ transformation. The surface layer of the cast slab and the tensile strength test specimen were observed by a transmission electron microscope (TEM) and it was revealed that (Ti, Nb)(C, N) is precipitated along the grain boundaries in the mild cooling, whereas in SSC, the precipitation of (Ti, Nb)(C, N) along the boundaries is suppressed and instead, they are uniformly dispersed and precipitated in a grain.[6]

The schematic view of the change in microstructure based on this finding is shown in **Fig. 7**. In the initial rapid cooling of SSC, precipitation of the ferrite phase is considered to start and simultaneously during this period, fine carbonitride is precipitated within a grain. The solubility product of (Ti, Nb)(C, N) is small and such change in microstructure is considered to be developed by such finely dispersed carbonitride becoming the nuclei of ferrite precipitation at the final stage of the secondary cooling.

2.5 Application to actual continuous casting

To the continuous casting machine for plate mill (No. 2 CC) at Kashima Works (**Table 1**), a rapid cooling zone was installed immediately below the mold and SSC was applied.[8] According to the radiation thermometer installed at the lower end of the rapid cooling zone, the cast slab surface temperature was about 1280 K in mild cooling, whereas the surface temperature was about 990 K in SSC, and the temperature transition that complies with SSC as shown in Fig. 3 was obtained and confirmed as intended.

The change of the state of occurrence of the transverse cracks pertaining to a transverse-crack sensitive steel grade bearing Nb, V, and Ni when SSC is applied is shown in **Fig. 8**. In either case of cast slab thickness of 235 mm or 300 mm, the suppression of transverse cracks is possible by the application of SSC.

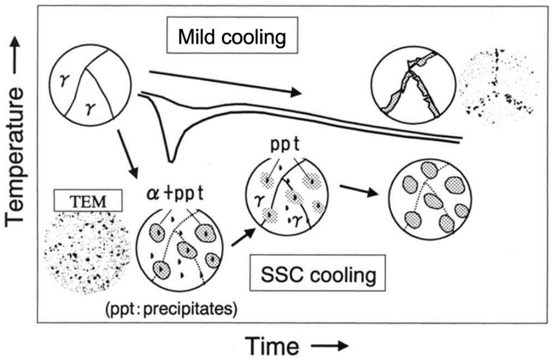

Fig. 7 Schematic view of change in microstructure with SSC

Table 1 Main specifications of No. 2 CC, Kashima Works

Item	Spec.
Type of machine	Vertical bending Height of vertical part 2.5 m
Machine length	28.3 m
Casting radius	9.4 m
Number of strand	Single

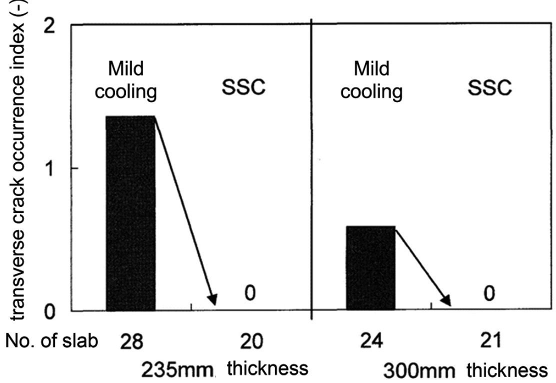

Fig. 8 Effect of SSC on the elimination of transverse cracking

3. Slab Center Porosity Suppression Effect of PCCS

3.1 Problem in the production of extra thick steel plates and history of development

Extra thick steel plates that exceed 100 mm in thickness are used for bridges, dies, large industrial machines, and so forth, and require high quality and soundness of internal quality. Particularly of late, the thickness of the steel plate for bridge retainers of the metropolitan expressway is increasing and more stringent internal quality is required. Furthermore, demand from the energy-related industry for the offshore structures of oil drilling has also been rising in recent years. When producing such extra thick steel plates, it is important to secure the internal quality. To secure the mechanical properties at the center part of a steel plate and to crimp the cast slab center porosity (voids), heavy reduction is applied in rolling.[9] However, in the conventional process of rolling of the conventional slabs cast by a regular continuous casting machine, due to the restriction of the rolling mill capacity, slight porosity defects remain even under the heavy reduction and are identified as defective by high-sensitivity ultrasonic testing. Therefore, the thickness of the producible steel plate is limited. Accordingly, conventionally in the past, extra thick steel plates were rolled from large sectioned ingots with a relatively large rolling reduction ratio. To solve this problem, we have developed the PCCS method[10] for a highly productive continuous casting machine to collapse the internal-quality-deteriorating slab center porosity in the continuous casting stage by applying heavy reduction to the cast slab at its final solidification stage. As a result, the production of extra thick steel plates via the conventional continuous casting and steel plate production process has been realized.

In the final stage of the solidification of liquefied steel, voids are developed due to volumetric contraction and remain in the slab center part in the form of center porosity. According to our investigation, in the ordinary slabs shown in **Fig. 9**, porosity of less than 2 mm in terms of equivalent circle diameter remains in an aggregated form in many cases. Therefore, depending on the size of the extra thick steel plate in which a sufficient reduction ratio is not available, the porosity remains even after rolling and is detected as defective in the ultrasonic testing. Therefore, reduction of the center porosity of slabs is a significant issue.

3.2 Framework of PCCS method

To solve the problem of cast slab defects in the production of the extra thick steel plates, in No. 2 CC, a regular continuous casting machine as specified in Table 1, the development of the PCCS

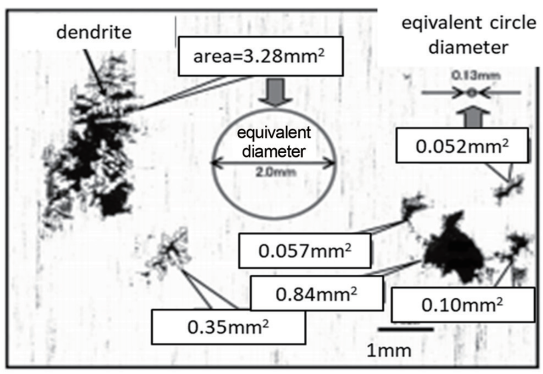

Fig. 9 Example of center porosity observed in conventional slab

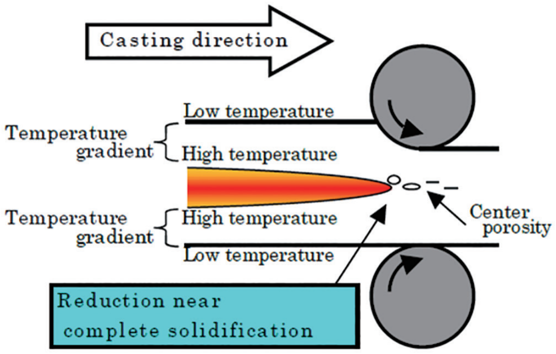

Fig. 10 Feature of PCCS at No. 2 CC, Kashima Works

Table 2 PCCS applying conditions

Item	Value
C content	0.09 – 0.15 mass% (400, 500, 600 MPa class)
Slab size	300 mm (t) × 2 300 mm (w)
Casting speed	0.55 – 0.60 m/min
Reduction amount	Approximately 10 mm

method was undertaken, the features of which are shown in **Fig. 10**. The PCCS method is used to crimp the center porosity at its formation stage by applying heavy reduction to a slab immediately before the slab thickness center part is completely solidified. The temperature difference between the cast slab center part and the surface is about 500°C. The method features the possibility of rendering effective reduction deformation to the center part having a higher temperature than that of the surface and collapsing the center porosity by crimping.

The PCCS application condition was studied with respect to the steel grades of carbon content of 0.09–0.15 mass % of 400, 500, and 600 MPa level (**Table 2**). The subject cast slabs were 300 mm thick and 2300 mm wide, the heaviest slab cast by 2CC. The casting speed was 0.55–0.60 m/min that was changed depending on the steel grade. A reduction of 10 mm was rendered to the slab in the later-described appropriate region wherein the center solid phase fraction is considered to be immediately ahead of the complete solidification.

3.3 Establishment of center porosity evaluation method

Upon developing the PCCS method, we quantified and evaluated the center porosity based on the following specific weight measuring method. With focus on the premise that porosity does not occur at the 1/4 thickness part of a slab, the porosity volume per unit weight of the center part is defined as the difference in the specific volume between that of the slab center part and that of the 1/4 thickness part, and calculated from Expression (1) where the slab center part density is denoted as ρ and the 1/4 thickness part density is denoted as ρ_0. ρ and ρ_0 are measured from samples 7 mm thick × 100 mm wide × 50 mm long. Further, the specific gravity measurement was conducted in accordance with the JIS Z8807 Methods for measuring the density and specific gravity of a solid[11] and the method of weighing in water was used.

$$\text{Porosity volume per unit weight} = 1/\rho - 1/\rho_0 \qquad (1)$$

Comparison of the porosity volume obtained by this evaluation method with the result of the ultrasonic testing (UST) applied to the sample taken from the same position at the center part is shown **Fig. 11**. In the UST testing, each volume of the sphere having the diameter of the circle with an area equivalent to that of the detected porosity image section was summarized with respect to all images, and the porosity volume per unit weight of a sample was obtained by dividing the total sum of the porosity volume by the sample weight. As a result, this evaluation method was confirmed as applicable as a simple method for center porosity evaluation.

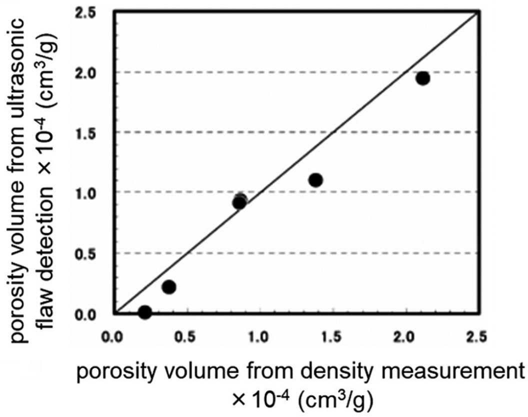

Fig. 11 Comparison of porosity volume measured with density and ultrasonic flaw detection

Furthermore, we also confirmed that this method of evaluating the porosity volume is applicable not only to slabs, but also to finished steel plates in a similar way. However, with respect to finished steel plates, the evaluation of porosity was conducted based on the porosity grade point organized to be proportional to the measured porosity volume.

3.4 Result of application of PCCS method

(1) Slab center porosity reduction effect

Figure 12 shows the result of the investigation on the relationship between the porosity volume and the solid fraction at the center part based on the solidification heat transfer calculation at the time of reduction. As **Fig. 13** shows, the cast slab applied with the PCCS method in the appropriate reduction region of 0.80−0.95 center solid fraction shows the great effect of the PCCS method of reducing the center porosity to about one third in any steel grades as compared with conventionally cast slabs.

(2) Verification of the effect of the PCCS method on the slab internal reduction

With respect to the macro-etch examination sample of a slab shown in **Fig. 14**, the negative segregation band (white band) produced by electromagnetic stirring is assumed as a boundary for convenience, and changes in the thicknesses of the center part and the upper surface between those of the slab applied with heavy reduction (PCCS method) applied onto the upper surface and those of the conventional slab without heavy reduction were investigated, and the internal reduction ratio was calculated.

In the center part of the slab applied with the PCCS method, the internal reduction ratio is about 3% and that of the upper surface side is about 0.7%. It is confirmed thereby that the internal reduction in the center part progressed on a priority basis and the effect thereof is higher.

(3) Effect on the reduction of finished steel plate center porosity

Figure 15 shows the relationship between the reduction ratio at rolling of the cast slab and the porosity grade. In the conventional method, a rolling reduction ratio of 5 is needed to obtain the porosi-

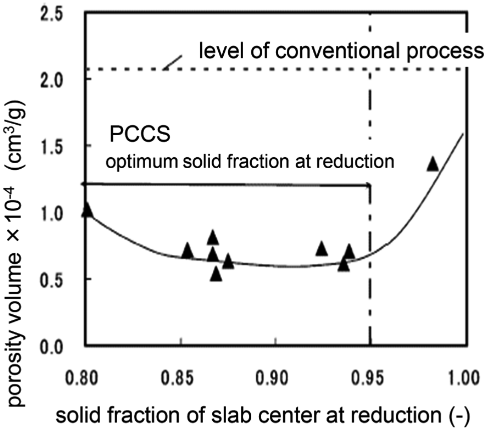

Fig. 12 Relationship between center solid fraction at reduction and porosity volume

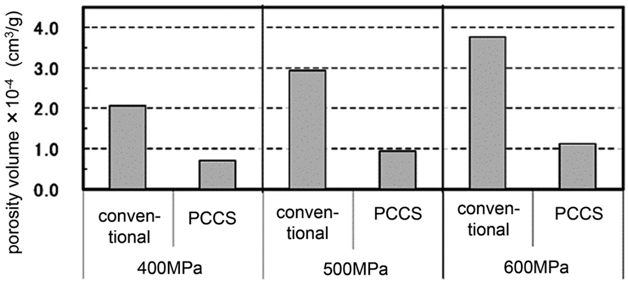

Fig. 13 Effect of PCCS on porosity volume

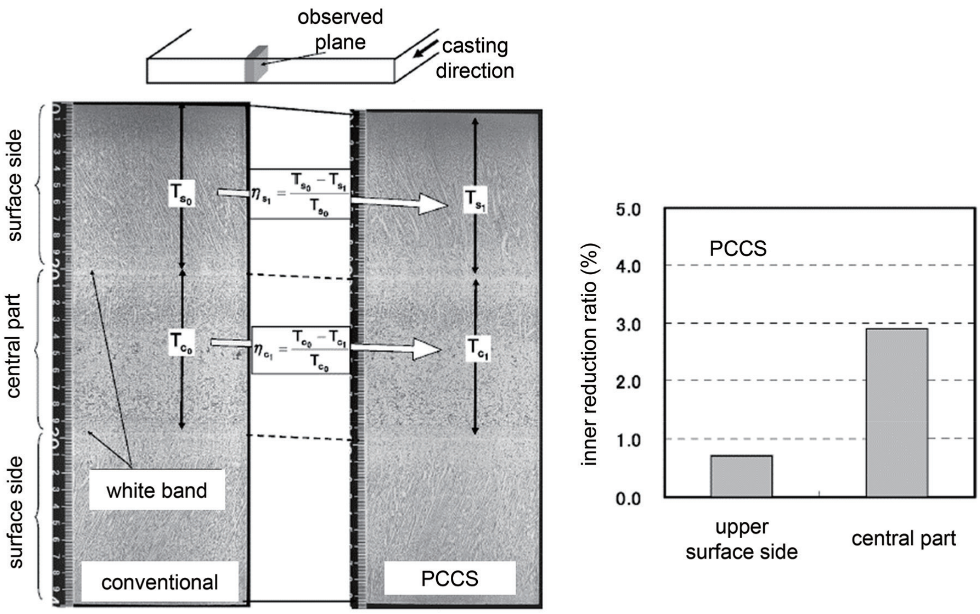

Fig. 14 Verification of internal reduction ratio *η*

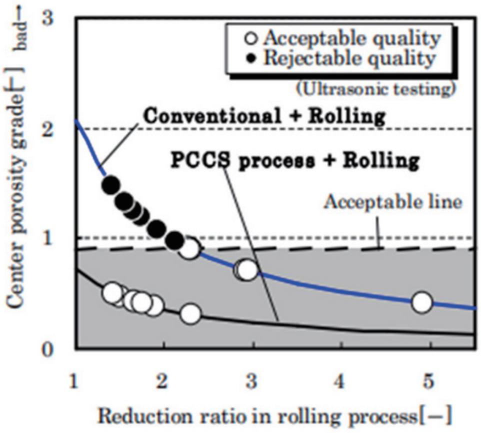

Fig. 15 Relationship between reduction ratio at rolling and porosity grade

ty grade of the same quality level and to this end, rolling of a large section ingot 750 mm thick is required. On the other hand, with a PCCS-applied cast slab, production of 150 mm-thick extra thick steel plates has become possible from a 300 mm-thick slab with a reduction ratio of about 2 (**Fig. 16**).

4. Ni-bearing Steel Slab Surface Quality Improvement

4.1 Background and framework

Since the high temperature brittle range of Ni-bearing steel expands towards the lower temperature side, it is necessary to select a casting condition incorporating these characteristics.[12] In particular, the 9% Ni steel plate for LNG tanks excellent in low-temperature toughness is of solidified single phase austenite (referred to as γ phase hereafter) and therefore, is susceptible to surface cracks, and various countermeasures for crack suppression have been taken. Results of various improvement efforts including that with secondary cooling improvement are reported hereunder.

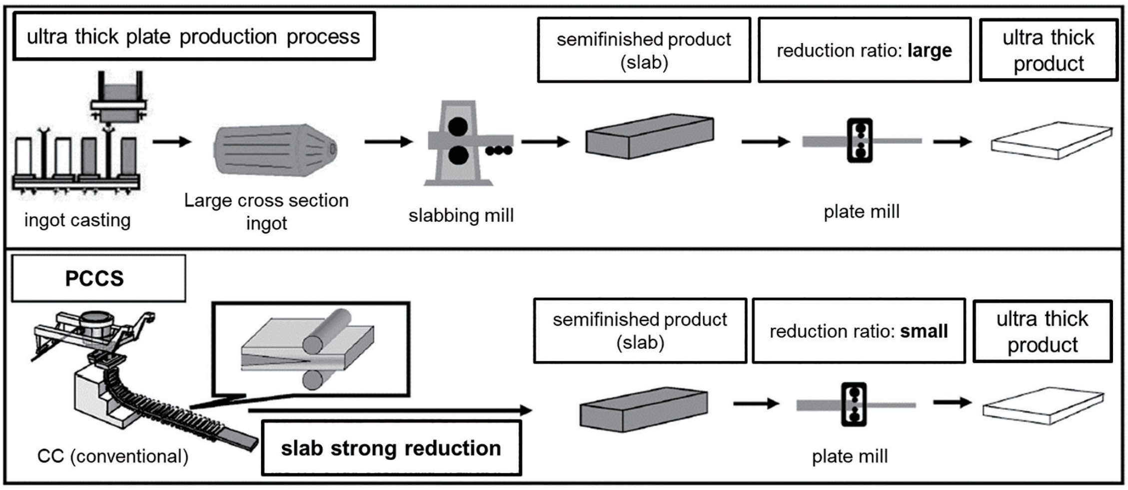

Fig. 16 Comparison of PCCS and ingot casting processes

Table 3 Casting conditions of 9% Ni steel

Slab thickness (mm)	235	250	300
Slab width (mm)	2260	2260	2300
Casting speed (m/min)	1.0	0.9	0.7

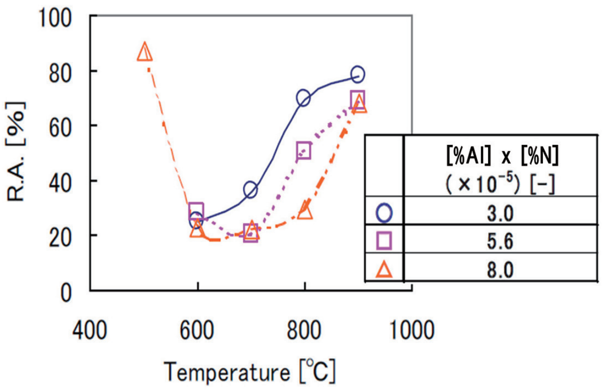

Fig. 17 Effect of [%Al] × [%N] value on hot ductility in 9% Ni steel slab

4.2 Slab surface quality improvement

9% Ni steel slabs of various sizes were cast by a continuous casting machine of the vertical-bending type with a 9.4 m radius of bending (**Table 3**). Since 9% Ni steel is of the solidified γ single phase, γ grain boundaries coincide with microsegregation sites and the steel is more susceptible to transverse cracks than general steels. In **Fig. 17**, hot ductility of 9% Ni steel is shown. Reduction of Area drops sharply below 900°C, however, R.A. in the neighborhood of 800°C is greatly improved under the condition of the reduced concentration product between Al and N. In **Fig. 18**, the transition of the surface temperature of the 300 mm-thick slab is shown. Taking into account the high temperature brittle range being expanded towards the lower temperature side, and for the purpose of reducing thermal stress, weak cooling casting was adopted to avoid the brittle range at above its higher temperature in the bending and unbending regions. At the corner the temperature becomes about 800°C of the brittle range and suppression of surface cracks by reducing Al and N concentrations was contemplated. In **Fig. 19**, the relationship between the product of Al, N concentrations, and surface quality is shown. By reducing Al and N concentrations, the slab surface quality (occurrence frequency of slab surface cracks is denoted by an index) has been significantly improved.

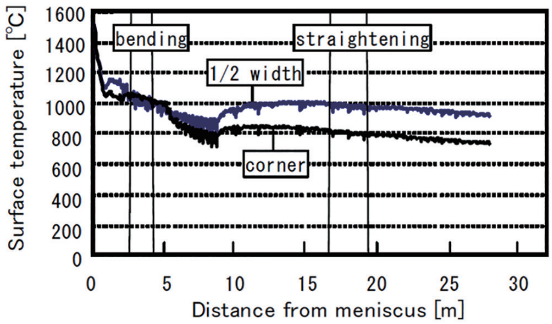

Fig. 18 Surface temperature of 9% Ni steel slab

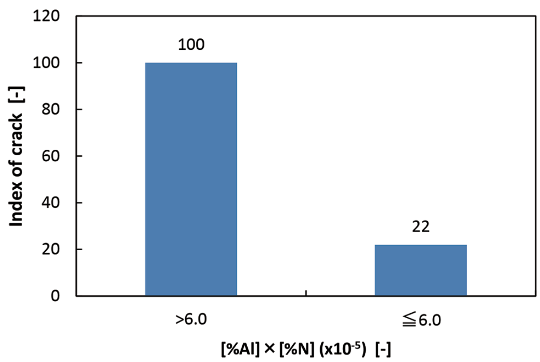

Fig. 19 Effect of [%Al] × [%N] value on surface quality index of 9% Ni steel slab

5. Result of Development and Conclusion

Various continuous casting technologies were developed for high grade steel plates to suppress the defects developed in the slab continuous casting process. The following have been clarified. Control of the microstructure of the cast slab surface layer is possible by utilizing the secondary cooling appropriately. By suppressing thereby the formation of the film-like ferrite developed along the grain boundaries that triggers cracks, embrittlement in the neighborhood of the γ to α transformation temperature can be eliminated and the transverse cracks on the surface of slabs are suppressed.

By applying the PCCS method that applies heavy reduction before the complete solidification at the thickness center part of the cast slab, significant reduction of the thickness center part porosity is realized. Accordingly, without using the conventional large section ingot as shown in Fig. 16, production of extra thick steel plates through the conventional continuous casting to steel plate rolling has been realized. Furthermore, by shifting the production process from the ingot-based to a continuous casting basis, reduction of CO_2 emission by 110 kg per ton of crude steel is expected, and therefore, the PCCS method is considered to be a process that contributes to the improvement of environmental loading. Hereafter, the method will continue to contribute to the stabilized supply of extra thick steel plates for the demand from offshore marine construction and so forth of the energy-related industry.

In the continuous casting of 9% Ni steel, by optimizing the secondary cooling condition, by implementing slab surface temperature control and by decreasing Al and N concentrations, remarkable reduction in surface cracks was observed. Thanks to the above developed technologies, highly efficient and highly productive manufacturing of slabs for high grade steel plates by a regular continuous casting machine was realized.

References

1) Kato, T., Ito,Y., Yamanaka, A., Baba, N.: Materia Japan. 45, 45 (2006)
2) Hiraki, S., Yamanaka, A., Shirai, Y., Sato, Y., Kumakura, S.: Materia Japan. 48, 20 (2009)
3) Mintz, B., Arrowsmith, J. M.: Met. Technol. 6 (1), 24 (1979)
4) Suzuki, H. G., Nishimura, S., Yamaguchi, S.: Trans. Iron Steel Inst. Jpn. 22 (1), 48 (1982)
5) Maehara, Y., Yasumoto, K., Sugitani, Y., Gunji, K.: Trans. Iron Steel Inst. Jpn. 25 (10), 1045 (1985)
6) Kato, T., Ito, Y., Kawamoto, M., Yamanaka, A., Watanabe, T.: ISIJ Int. 43, 1742 (2003)
7) Ito, Y., Kato, T., Yamanaka, A., Watanabe, T.: Tetsu-to-Hagané. 89, 1023 (2003)
8) Baba, N., Ohta, K., Ito, Y., Kato, T.: 5th European Continuous Casting Conference Proceedings, 2005, p. 160
9) Emoto, K.: Edited by the Iron and Steel Institute of Japan: 86th and 87th Nishiyama Memorial Technical Lecture, 1982, p. 63–64
10) Sato, Y., Kumakura, S., Ohta, K., Hiraki, S., Shirai, Y., Yamanaka, A.: CAMP-ISIJ. 21, 104 (2008)
11) JIS Handbook. JIS Z8807. Japanese Standards Association, 2007
12) Kato, T., Kasai, N., Kawamoto, M., Yamanaka, A., Watanabe, T.: Tetsu-to-Hagané. 84 (12), 856 (1998)


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