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Expansion of Steelmaking Capacity at Oita Works

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Abstract

Since its inauguration in 1972 as a 100%-CC integrated steelworks, Nippon Steel Corporation's Oita Works has endeavored to enhance quality manufacturing capacity, improve productivity, reduce costs, and increase the ratio of hot charge rolling. Such measures, as found in Oita Steelmaking Plant, include the "Direct Link Process V" commissioned in 1980, consisting of large-section, constant-width slab casting on Nos. 4 and 5 continuous casters and a directly coupled sizing mill for heavy width reduction, and the converter-type multi-function hot-metal pretreatment introduced in 2002, which replaced conventional ladle type hot metal dephosphorization. As a result, an annual steel production record of 9.634 Mt was marked in the fiscal year 2010 (ending Mar. 2011), including a monthly production record of 0.905 Mt in March 2011; the Plant is virtually capable of producing 10 Mt of steel per annum, one of the largest single steelmaking plant in the world. This paper presents the measures taken in the steel refining, continuous casting and sizing rolling processes of the Plant; these measures increased production capacity by roughly 120,000 t per month in six years (i.e., from 2005 to 2010).

1. Introduction

Nippon Steel Corporation's Oita Works, inaugurated in 1972 as a 100% continuous-casting works, commissioned in 1980 a system called the "Direct Link Process V", wherein Nos. 4 and 5 continuous casters (CCs), operating in a large-section constant-width regime, were directly linked to a sizing mill (SM) for heavy width reduction. In 2002, Oita Works switched the hot metal dephosphorization process from the conventional method using hot metal ladles as the reaction vessels to the "multi-function refining converter (MURC)" process. Such changes in the steelmaking structure enhanced the process capacity to incorporate desired quality in slabs, raised productivity, and reduced costs.[1-6] **Fig. 1** shows the historical change of annual crude steel production of the Works since its inauguration and the rolling tonnage of the SM. Oita Steelmaking Plant marked an annual crude steel production record of 9.634 Mt (all units herein are metric) in the fiscal year 2010 (ending in March 2011), and a monthly record of 0.905 Mt in March 2011. Thus, Oita Steelmaking Plant has virtually attained a production capacity of 10 Mt/y, the world highest level for a single steelmaking plant, and continues to serve as one of the principal steelmaking plants of the company.

This article presents the principal measures for production increase of the steel refining, continuous casting, and sizing rolling processes of the plant that brought about an increase in the monthly

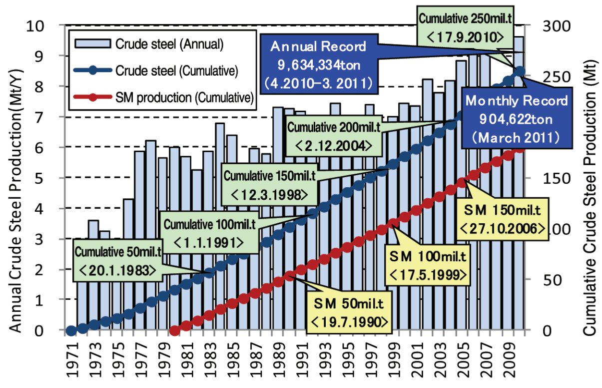

Fig. 1 Slab casting and sizing mill rolling at Oita Works

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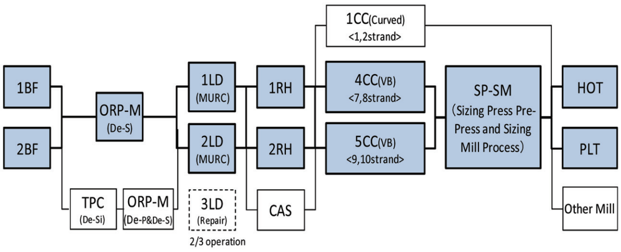


Fig. 2 Process flow of Oita Steelmaking Plant

throughput of roughly 120,000 t over a six-year period from 2005 to 2010 without incurring large-scale investments for new facilities.

2. Production Capacity of Oita's Steelmaking Plant

Fig. 2 shows the process flow of Oita Steelmaking Plant. The Plant is characterized by the Direct Link Process V—which incorporates five directly linked production steps: namely (I) LD converters (or BOFs), (II) secondary refining, (III) CC, (IV) SM, and (V) rolling—as well as the MURC process, the converter-type hot metal pretreatment introduced in 2002, and 100% application of RH degasing. The plant now enjoys quality superiority, high productivity, cost competiveness, and high hot-charge-rolling (HCR) ratios, on account of the measures for optimizing the steel refining processes.

After the above, the plant embarked upon measures to increase the production capacity further by 120,000 t per month. More specifically, the measures included the following: (i) regarding the refining process, an increase in the heat size, a decrease in the cycle time, and an increase in the working ratio of the converters; (ii) regarding Nos. 4 and 5 CCs, a decrease in the casting time per charge by increasing casting speed and slab width, an increase in the SM capacity accordingly, an increase in the number of sequential casting, an increase in the net working rate, and an increase in the casting yield; and (iii) regarding No. 1 CC, an increase in productivity by adding facilities for HCR. As a result, the throughput of the plant was increased by 120,000 t per month, approximately, to reach 880,000 t per month. These measures are explained in more detail in the following sections.

3. Philosophy regarding the Productivity Increase of Steel Refining Processes

3.1 Roles of refining processes and measures for productivity increase

Efforts have been made at Oita Works since 2002 to increase the application of the converter-type hot metal pretreatment and the MURC process, even in a period of high production at low hot metal ratios, aiming at fully enjoying the benefits of the pretreatment.[4] As seen in **Fig. 3**, via the MURC process, desiliconization and dephosphorization are done under oxygen blowing, and then after discharging the slag that forms during the blowing, decarburization is done under oxygen blowing in the same converter vessel. This process has a problem in that because of the intermediate discharge of the slag, as well as the cooling and solidification of the decarburization slag for its reuse for the following charge, the productivity of the converter is likely to fall. For this reason, in the study for enhancing the steel refining productivity, an operation practice was looked for that would increase production, cut costs, and minimize slag formation, while maintaining a high hot metal pretreatment ratio, even during high production.

Table 1 Measures for improving converter productivity

Content	BOF productivity		
	Heat size*	Cycle time	Utilization
Before improvements (2003)	375 t/ch	37.0 min	86%
New ladle, crane upgrade	+28 t/ch	+1.0 min	
Bigger de-slagging pot		−1.4 min	
Time reduction of slag solidification		−0.2 min	
IDF upgrade (1LD and 2LD)		−1.2 min	
Refractory repair improvement			+1.9%
Improved (2009 -)	403 t/ch	35.2 min	87.9%

* In terms of cast slabs

Table 1 shows the measures taken in the steel refining processes to achieve a monthly production of 880,000 t. The following measures were taken for the converters so that a good balance is kept between the blast furnace production, which had been increased through relining, and the throughput of the continuous casters: (i) increase in the heat size; (ii) decrease in the cycle time; and (iii) increase in the utilization ratio (net working ratio). These measures proved effective at enhancing the productivity while keeping the hot metal pretreatment ratio at a high level.

3.2 Increase in heat size

The heat size of Oita's converters was increased twice in the last 10 years, as shown in **Fig. 4**. The first enlargement was during the introduction of the MURC process in 2002 mentioned earlier. As a result of the intermediate discharge of the desiliconization and dephosphorization slag and the cooling and solidification of the decarburization slag, the converter cycle time became longer than before; to avoid the consequent decrease in production capacity, the heat size was increased from 340 to 375 t so as to keep a good balance with the casters. Through the second enlargement in 2006, the heat size was further increased by 20 t. On this occasion, molten steel ladles were replaced with larger ones, and the capacity of the crane of the tapping bay was also increased. Thanks to the large, two-step in-

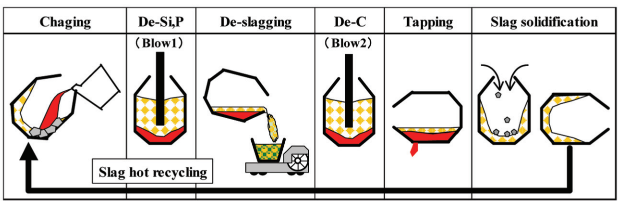


Fig. 3 MURC process flow

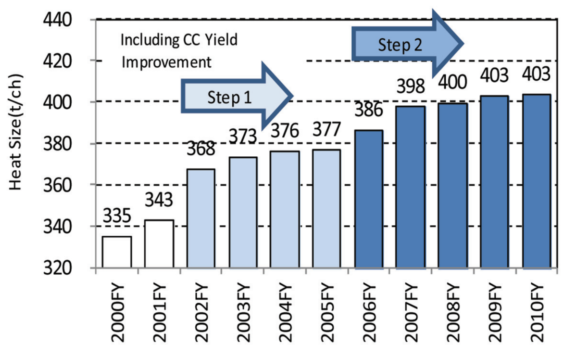


Fig. 4 Change of heat size

crease in the converter heat size and the measures for the continuous casters to increase the prime slab yield, the production per charge was increased from 340 to 403 t in terms of prime slab.

3.3 Decrease in converter cycle time

The cycle time of Oita's converters had been previously shortened by visualizing the inside conditions of the vessel using various sensors.[6] For the production capacity increase, the cycle time was further shortened by reducing the time mainly of the intermediate deslagging and the solidification of the decarburization slag of the MURC process and the blowing for decarburization, which accounts for a large part of the cycle time.

(1) Shortening of intermediate deslagging time

By the MURC process, after the blowing operation for desiliconization and dephosphorization, the molten pig iron is kept in the vessel and only the slag that has formed during the operation is discharged to a slag pot by tilting the vessel; the deslagging is accelerated by the slag foaming due to CO gas generation. Here, the slag pot is required to have enough capacity for receiving all foaming slag; however, the slag pot was too small and the converter tilting speed for deslagging was restricted to avoid slag overflow. If deslagging is incomplete, P in the slag will be carried over to the subsequent decarburizing blowing, leading to undesirable increase in CaO consumption and excessive slag formation. The capacity of the slag pot was expanded as a measure to accelerate the tilting to shorten the deslagging time and thus fully enjoy the advantages of the MURC process.

Fig. 5 schematically illustrates the measure taken. The slag pot capacity was increased to about 1.5 times while avoiding interference with the tilting of the converter vessel. As a result of increase in the tilting speed, the intermediate deslagging time became shorter by an average of 1.4 min. Then, the solidification time of the decarburization slag was made shorter. The slag solidifying agent had been charged into the converter using a vibrating feeder, and the charging time was governed by its feeding rate. This was changed into a cut-gate-type feeder that could dump a prescribed quantity at one stroke. By this, the charging time was decreased by an average of 0.2 min. Thanks to these measures to shorten the time for the steps peculiar to the MURC process, the converter cycle time was made shorter by 1.6 min (see **Fig. 6**).

(2) Decrease in decarburizing time

Oita Steelmaking Plant operates two converters out of three, but the capacity of the induced draft fan (IDF) and the duct diameter of the gas recovery system (i.e., the OG system) were different from converter to converter: the exhaust gas suction capacity of Nos. 1 and 2 Converters was 242,000 and that of No. 3 was 313,000 Nm^3/h. As a consequence, the maximum oxygen-blowing rate of Nos. 1 and 2 in the decarburization stage was limited to 80,000 Nm^3/h because of the suction capacity, whereas the same of No. 3 was 95,000 Nm^3/h, limited only by the oxygen generation capacity. In addition, because of the limited oxygen generation capacity, decarburization blowing of two converters simultaneously was impossible. For this reason, the total oxygen-blowing rate for the two converters was set at 80,000 Nm^3/h, and the operating cycles of the two converters were controlled such that their decarburizing periods would not lap over each other.

To remove the restriction, the IDF capacity of Nos. 1 and 2 Converters was increased from 242,000 to 272,000 Nm^3/h, which made it possible to increase the oxygen-blowing rate to 95,000 Nm^3/h—the maximum defined by the oxygen generation capacity. In addition, for oxygen blowing at the increased rate, the nozzle diameter

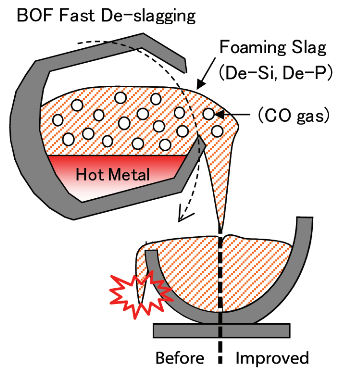


Fig. 5 Reduction of intermediate deslagging time

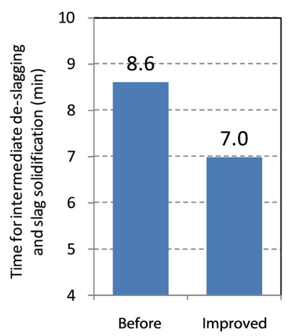


Fig. 6 Change of intermediate deslagging and slag solidification time

of the main lace was increased and the lance gap was optimized. As a result, the converter cycle time was shortened by 1.2 min.

3.4 Increase in net working ratio

By the year 2005, the ratio of converter non-working time was decreased to approximately 14% thanks to measures such as wide application of sensors to detect the conditions inside the vessels.[6] Repair of converter refractory accounts for a major part of non-working time, more specifically, flame spraying and gunning of refractory lining and the coating repair on the charging side. The measures to increase the net working ratio focused on these two kinds of refractory repair work.

The problem with the flame spraying and gunning was that not only very limited time could be spared for refractory repair but also the work efficiency was too poor for the time available. Measures were taken to shorten the preparation time of the spraying machine, and the machine was modified to double the capacity. As a result, the frequency of repair work was decreased, and the net working ratio was increased. As for gunning, a movable refractory gunning machine had been provided, but its movement and positioning were too slow, resulting in an extremely long preparation time. As a solution, a fixed gunning machine was installed on the back side of each converter. These measures shortened the refractory repair time and the non-working time as refractory repair was reduced by about an average 0.9% with respect to calendar time.

The converter wall on the charging side was repaired by charging of coating material using a scrap chute. This operation delayed the scrap charging of the following heat, causing the net working ratio to decrease. As countermeasures, the charging-bay crane exclusively for charging the coating material was coupled with the scrap charging crane, and a special chute was provided for the coating material. Through these measures, it became possible to transport

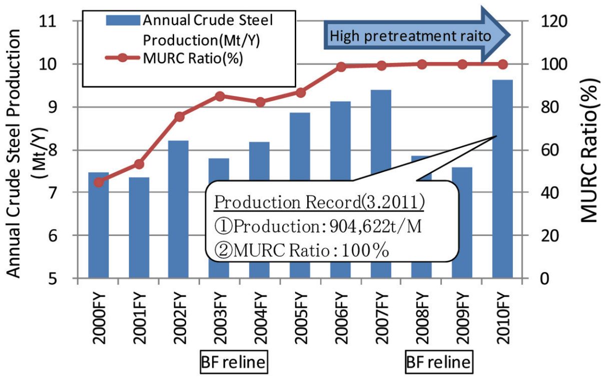


Fig. 7 Crude steel production and MURC ratio

the coating material and scrap at the same time. In addition, the repair time was shortened, and the net working ratio of the converters was improved by an average of approximately 1.0%.

3.5 Section summary

As a result of the heat size increase, shortening of the cycle time and improvement in the net working ratio of the converters, the steel production capacity of Oita Works increased from 762,000 to 880,000 t/month; a monthly production record of 904,622 t was marked in March, 2011. In addition, as seen in **Fig. 7**, the application ratio of the MURC process was kept high before and after the production increasing measures, which were instrumental in improving the converter productivity, environment conservation, cutting production costs and maintaining labor productivity at a high level.

4. Philosophy regarding the Productivity Increase of Continuous Casting Processes

4.1 Measures for productivity increase of continuous casting

Table 2 lists the measures taken at Oita Works to enhance the productivity of continuous casters over the last five years. The casting speed was raised and the slab width of Nos. 4 and 5 CCs was enlarged to increase the production capacity, and the rolling capacity of the SM was also increased accordingly. Nos. 4 and 5 CCs were built to partially different specifications, and for this reason, some steel grades could be cast through only one of them. Then, the casters were modified to the same specifications, and the steel grade restriction was relaxed so as to increase the number of heats of tundish (or charges of sequential casting). As for No. 1 CC, facilities for HCR were provided so that the caster could produce slabs for plate-mill products. Additionally, measures were taken to shorten casting time and increase the number of charges of sequential casting. These production increasing measures are explained below in more detail.

4.2 Increase in throughput of Nos. 4 and 5 casters

(1) Raising Maximum Casting Speed to 1.8 m/min

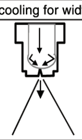
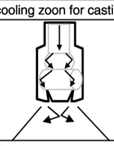
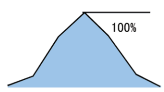
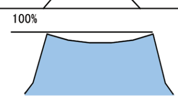
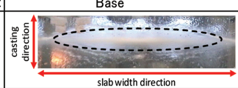
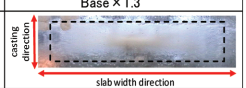
To raise maximum casting speed, two-slit type cooling nozzles having high cooling ability were developed. The spray angle in the casting direction was narrow with the old type nozzle and the cooling ability was insufficient, whereas the mist jets from two slits of the developed nozzle collided with each other and spread in a wider angle; as a result, the area of spray cooling increased and that of air cooling before and after the spray cooling zone decreased, which suppressed the recuperation of the cast and thus increased the overall cooling efficiency. **Table 3** shows the features of the developed nozzles, and **Fig. 8** the relationship between spray conditions and the heat transfer coefficient obtained through actual measurement. The measurement made it clear that the cooling efficiency of the new nozzle in a high water volume range is higher by about 30% than that of the old one. In addition, the new nozzle is applicable to all zones along the machine length because of a smaller nozzle head diameter, and capable of using the same air/water ratio. In appreciation of these advantages, the new nozzle was used in all the curved sections, where the most part of secondary cooling is done. As a result, the maximum casting speed was raised from 1.5 to 1.7 m/min. To increase the casting speed yet more, the slab cooling in the segments of the horizontal sections after the unbending point was intensified by providing direct mist cooling. It was feared that internal

Table 2 Measures for improving CC productivity

CC	Year	Measures	CC productivity: Casting time	Heat/DB	Utilization
4CC & 5CC		Before improvement	40.5 min/ch	9.5 ch/DB	87.9%
	2006	Enlargement of casting width for plate (revamping only 4CC)	▲0.3 min/ch		
	2006-2009	Max casting speed 1.5→1.8mpm (2-slit nozzle, UBP roll pitch shortening and revamp of secondary cooling after UBP)	▲1.0 min/ch		
	2009	Enlargement of casting width (upgrade of SM-RF and rolling stand)	▲0.9 min/ch		
	2009	Enlargement of casting width for plate (revamping 5CC for easy cast positioning)		○0.5 ch/DB	
	2009	Wider plate casting (4CC and 5CC)	▲0.3 min/ch		
	2010	Revamp for best product mix (1CC-HCR operation)	▲0.1 min/ch		
	2010	Reduction of preparing time for casting (4CC and 5CC)			○0.6%
		Improved	37.9 min/ch	10.0 ch/DB	88.6%
1CC		Before improvement	79.1 min/ch	2.0 ch/DB	
	2010FY	Revamping for best product mix, plate casting (1CC-HCR operation)	▲0.7 min/ch		
	2010FY	Revamping for best product mix, plate casting (1CC-HCR operation)		○0.3 ch/DB	
		Improved	78.4 min/ch	2.3 ch/DB	

○ : Good

Table 3 Comparison of single- and double-slit nozzles

	1-Slit Nozzle (Conventional)	2-Slit Nozzle (Developed)
Design concept	Uniform cooling for width direction	Expand cooling zoon for casting direction
Nozzle spray pattern (in casting direction)		
Water distribution (in casting direction)		
Influence of water volume	Reduction of cooling area at high water volume	Uniform cooling area
Turndown	~20	~20
Heat transfer coefficient	Base	Base × 1.3
Spray distribution		
Others	–	· Uniform and wide cooling area · Small nozzle head → Easy application
Evaluation	Base	Superior

cracks might occur in No. 5 segment at high casting speeds, and as a countermeasure, the roll pitch in the segment was made smaller. This controlled the total strain below the critical strain (see **Fig. 9**), and the maximum casting speed was increased from 1.7 to 1.8 m/min.

(2) Expansion of casting width

Slabs cast on Nos. 4 and 5 CCs undergo heavy width reduction through the SM (see **Fig. 10**), and then fed to the rolling mills in and outside the Works. In this relation, aiming at increasing the capacity of the SM line, keeping high yield, increasing the casting width of the CCs, and enhancing the productivity, the following equipment modifications were introduced: (i) increase in the heating capacity of the reheating furnace between the CCs and SM; (ii) renewal of the drive motor for the horizontal rolls; and (iii) installation of a sizing press (SP). The heating capacity of the reheating furnace was increased by installing blowers for COG and combustion air, and an IDF was additionally provided in the exhaust system to intensify the draft force.

As a result, the COG flow was increased from 20,000 to 24,500 Nm^3/h, the heating rate as calculated from furnace temperature measurement was raised to 5°C/min, and it became possible to apply heavier reduction per pass. In addition, as a result of the above renewal of the drive motor for the horizontal rolls, the rolling speed was increased by about 26%, reducing the cycle time per slab by 0.5 min. Fishtails at the head and tail ends of slabs resulting from heavy width reduction through the SM had constituted a problem since long (see **Fig. 11**). To shorten the fishtail length, a sizing press was installed to apply two-step width reduction corresponding to the heavy pre-press reduction on the SM to both the head and tail ends (see **Fig. 12**). This forming method reduced the crop loss due to the fishtails by 65%, making it possible to apply heavy width reduction without causing significant yield loss.[7]

(3) Shortening of preparation times of Nos. 4 and 5 casters

To shorten the preparation time of the casters, the time for extracting the final slab of the last charge was reduced by intensifying the cooling of the top crop part only while preventing overcooling

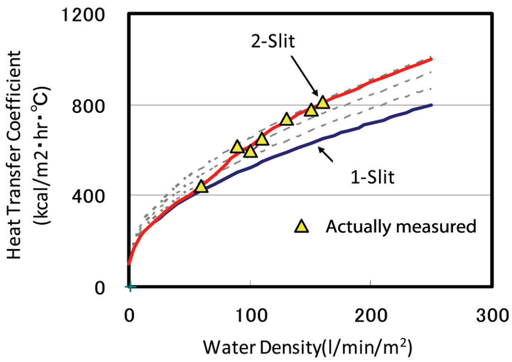


Fig. 8 Effects of cooling nozzles (on heat transfer coefficient)

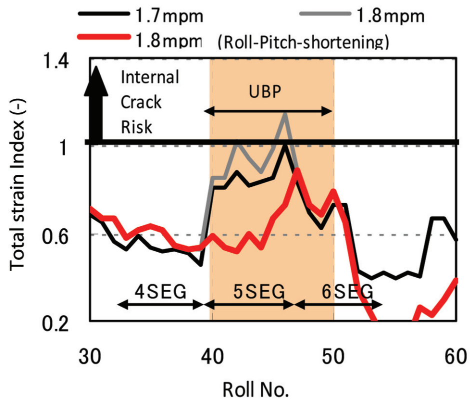


Fig. 9 Effect of roll-pitch shortening at unbending point on the distribution of total strain obtained by numerical calculation

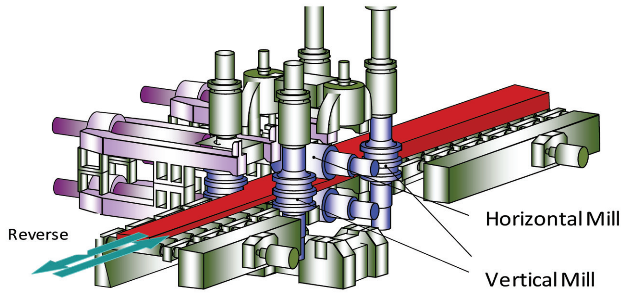


Fig. 10 Overview of sizing mill

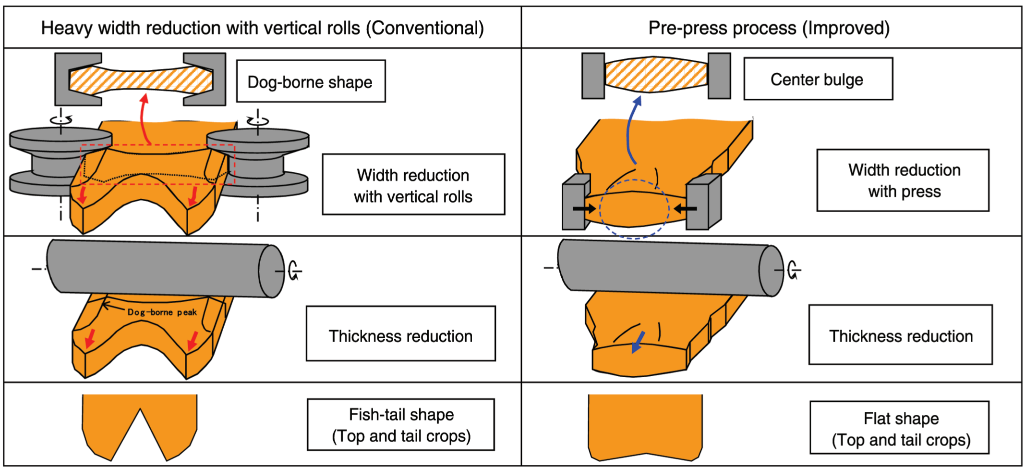


Fig. 11 Fishtail forming during sizing rolling and countermeasure

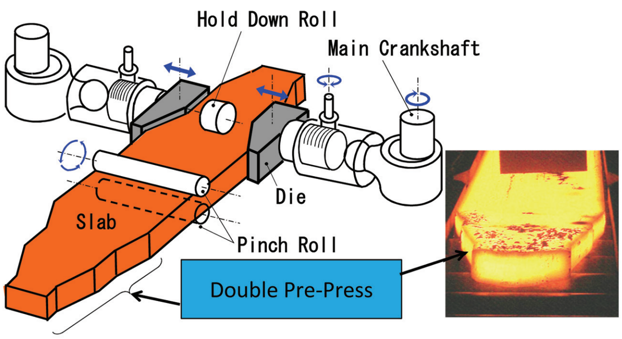


Fig. 12 Prepress width reduction at sizing press

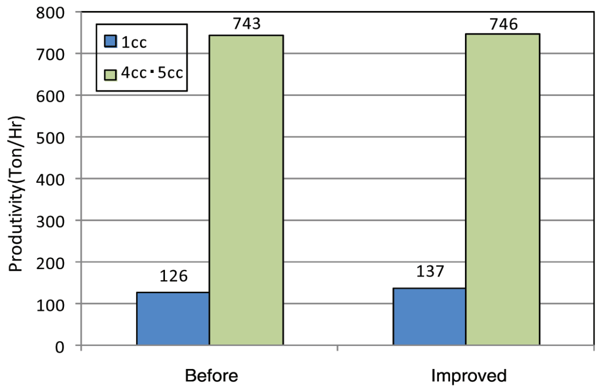


Fig. 13 Effect of HCR operation at 1CC

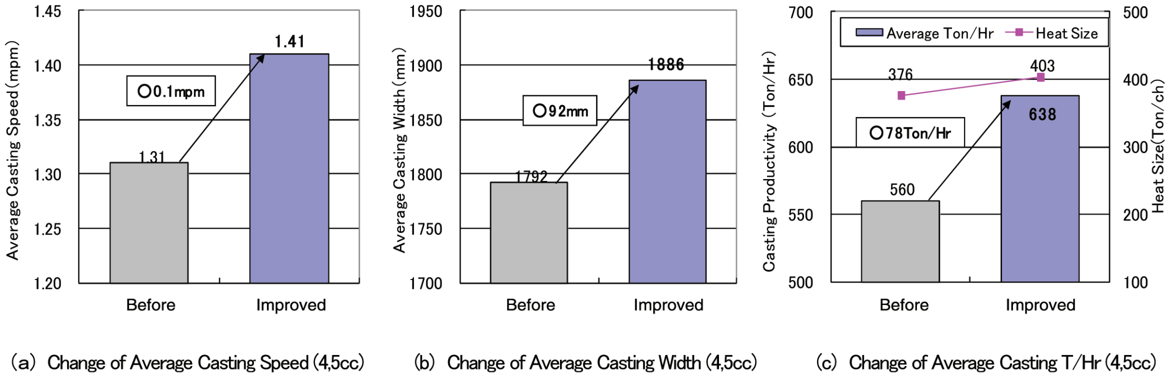


Fig. 14 Improvement of operation results

of the other parts by segmentalizing the cooling control sections of Nos. 5 and 6 zones. In addition, the length of the dummy bars was reduced from 14.7 to 12 m. These measures jointly decreased the preparation time from 37 to 33.4 min.

4.3 Optimum allocation of steel grades to casters

No. 1 CC was used to produce slabs mainly for hot strip mill and those to be sent to other works. Therefore, the slabs were left to cool and after surface conditioning were stored in slab yards. For this reason, the caster was not linked to the HCR route. To make the production structure more flexible, a HCR route linking No. 1 CC with the hot strip mill and the plate mill was constructed; the new route comprised inspection tables, transfer equipment (an automatic handling (or carry-out) crane and lorries for hot-slab pallets), and a gas cutter to divide slabs for plate rolling, arranged separately so as not to disturb the materials transfer of the existing route. Based on the new slab handling structure, the allocation of steel grades to the continuous casters was reviewed, as a result of which No. 1 CC became responsible for large-width slabs for the plate mill and Nos. 4 and 5 CCs for slabs for the hot strip mill, which are in large sections and cast at high t/h. These measures brought about capacity increase of the casters, leading to an increase in the total monthly production capacity of the three casters of 14,000 t (see **Fig. 13**).

4.4 Section summary

As a result of the measures taken on the casters and the sizing mill described above, the operation results of Nos. 4 and 5 CCs improved significantly as seen in **Fig. 14**. The monthly production capacity of the three continuous casters was increased by 110,000 t to reach a level of 880,000 t per month.

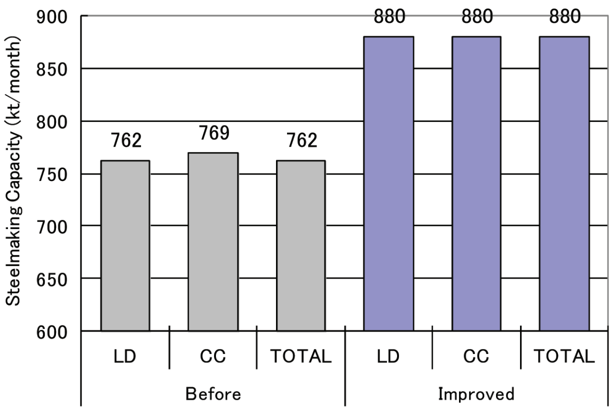


Fig. 15 Improvement of total capacity of steelmaking plant (2005-2010)

5. Closing

As a result of the measures taken at Steelmaking Plant of Oita Works described above, the integrated production capacity of the steel refining, continuous casting and sizing rolling processes was expanded by about 120,000 t/month over the six-year period from 2005 to 2010 (see **Fig. 15**). A monthly production record of 904,622 t (in terms of cast slabs) was marked in March 2011, which indicates that the plant is now capable of producing 10 Mt of steel per annum, the highest among single steelmaking plant of the world. The Works will continue to bend further efforts to pursue higher productivity and excellence in quality and cost competitiveness to remain among the best steelmaking plants of the world.

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