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Latest Plate Production Technology of Nippon Steel & Sumitomo Metal Corporation

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Abstract

Heavy steel plates are required to have increasingly advanced and diversified functions, and in response, the two forerunners of Nippon Steel & Sumitomo Metal Corporation developed wide varieties of plate manufacturing technologies of their own. Such technologies have brought about synergistic effects to accelerate technical development after the merger. In the processes of slab heating, plate rolling, and cooling, advanced numerical models have been worked out to reduce energy consumption, raise product yield, and enhance process control accuracy. The companies developed their own versions of thermo-mechanical control processes (TMCP) and equipment capable of accurately and evenly cooling plates within a wide range of cooling rates. Advanced vertically integrated quality control systems support the plants to appropriately respond to customer requirements in a timely manner.

1. Introduction

Steel plates are being used under increasingly tough conditions with the latest increase in energy demand. Such tough use conditions include those in arctic regions and deep waters; accordingly, low-temperature toughness, ultra-heavy gauge, and other new property items came to be required for the product in addition to high strength, which fact calls for innovative process technologies. In view of growing demand for plate products, new plate mills have been constructed and the production capacities of various others increased in China and Korea. Consequently, Japanese plate manufacturers have to further cut their production costs. In consideration of such latest market change, Nippon Steel Corporation and Sumitomo Metal Industries Co. Ltd., the predecessors of Nippon Steel & Sumitomo Metal Corporation, developed and fostered wide varieties of technologies for plate manufacturing processes.[1)] The present paper outlines distinctive ones of such technologies.

2. Slab Heating Control

As reheating furnaces were added to the plate mill lines to meet the increasing demands for heavy plates for energy-related applications, improvement of fuel consumption became an important issue. To reduce unit consumption of fuel, automatic combustion control models have been developed.[2)] For slab temperature calculations, a simplified three-dimensional heat transfer model has been established wherein two-dimensional calculations in the thickness and length directions and another in the thickness and width directions (both using two-dimensional heat transfer equations) are combined (see **Fig. 1**).

Based on this slab temperature calculation model, an automatic combustion control model has been proposed. **Figure 2** shows the concept of furnace temperature control by the model. A temperature pattern of a tail-heavy type is adopted whereby the furnace temperature is set as low as possible on the entry side: the furnace temperature is controlled so as to hit a target slab center temperature at the discharging end in consideration of the slab center temperature and the degree of soaking (the temperature difference between the slab

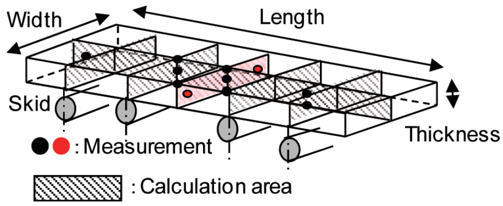

Fig. 1 Scope of slab temperature calculation

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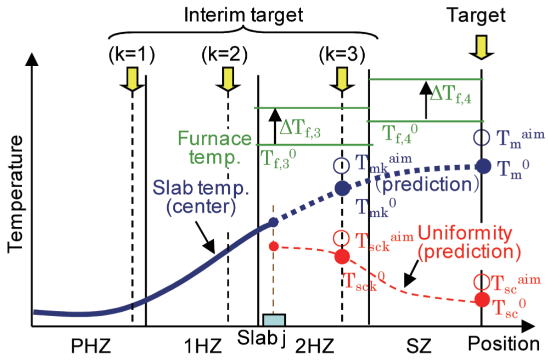

Fig. 2 Concept of furnace temperature control

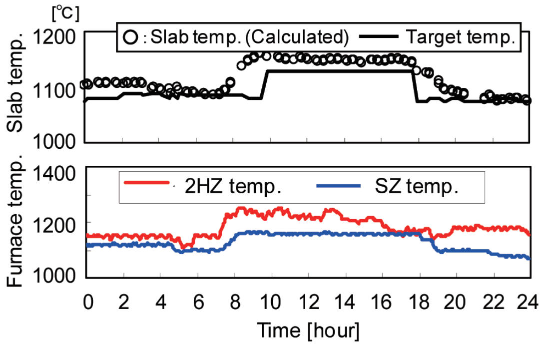

Fig. 3 Application example of automatic combustion control

center and the lower surface) in the middle furnace position. For example, in the case of slab j in Fig. 2, the temperature rise $\Delta T_{f,3}$ in the No. 2 heating zone (2HZ) and the same $\Delta T_{f,4}$ in the soaking zone (SZ) are determined by the linear programming based on (a) the difference between the final slab temperature T_m^0 expected at position k=3 and the target discharge temperature T_m^{aim}, (b) the difference between the expected soaking degree T_{sc}^0 and the target soaking degree T_{sc}^{aim}, (c) the difference between the expected slab temperature T_{mk}^0 and the aimed slab temperature T_{mk}^{aim} at k=3, and (d) the difference between the expected soaking degree T_{sck}^0 and the aimed soaking degree T_{sck}^{aim} at k=3.

Figure 3 shows an actual temperature record of a reheating furnace working under automatic combustion control. The model makes it possible to get the target slab discharging temperature without insufficient heating by minutely controlling the furnace temperature in the 2HZ. As the application ratio of the automatic control increases, the unit fuel consumption has improves by 2.5% from that by conventional manual control.

3. High-precision Rolling Control

High-functionality plates, typically those of high-strength steels, are manufactured usually by applying the thermo-mechanical control process (TMCP) to steels containing alloy elements in high quantities. Because their hot deformation resistance is very high, the number of rolling passes increases and it is hard to obtain high dimensional accuracy in terms of gauge, flatness, etc. In addition, because of high contents of alloy elements, unit steel cost is high, and a small decrease in production yield results in considerable loss. Some examples of measures taken in plate rolling to secure desired quality of high-functionality products are presented in this subsection.

3.1 Shape control

Controlled rolling (CR) of plates in Japan started in the 1960s. As it became widely practiced, the increase in the rolling load due to low-temperature rolling became conspicuous, and equipment such as the mill housing was damaged. To prevent such troubles, plate mills became larger through reinforcement of housings and other measures. More recently, new shape-controlling mills such as pair-cross (PC) mills were built, which has made it easier to practice controlled rolling at high reduction and achieve good flatness and dimensional accuracy.

Figure 4 [3] shows a conceptual diagram for setting the pass schedule of plate rolling. In step 1 (in circle in the diagram), the rolling load at the final (n-th) pass is defined based on the product thickness and the target plate crown, then in step 2, the reduction to obtain the final rolling load is calculated, and the plate thickness h_{n-1} at the exit from the previous ((n−1)-th) pass is determined, and in step 3, the rolling load at the (n−1)-th pass is determined such that the crown ratio (as defined in **Fig. 5**) is kept unchanged and flatness is not disturbed. The entire pass schedule for a slab is determined by thus repeating steps 2 and 3 backwards from the final pass (pass scheduling for constant plate crown). Naturally, if the calculation result exceeds the upper limits of the rolling load, torque, etc. of the mill, they must be adjusted to fall within the mill capacity.

For heavy-reduction rolling of plates, it is necessary to adequately control the plate crown at the final pass (determined in step 1) and keep the crown constant (step 3 above), and the use of shape-controlling mills capable of changing plate crown during rolling is increasing for this reason; in fact, Nippon Steel & Sumitomo Metal operates a back-up roll bending (BURB) system at Nagoya Works [4] and a PC plate mill (shown in **Fig. 6**) at Kimitsu Works.[5]

A PC mill controls plate crown by turning the upper set of rolls (work roll (WR) and back-up roll (BUR)) horizontally in one direction and turning the lower set of rolls (same) in the opposite direction such that they cross each other on the mill center line. The roll pass schedule calculation for a PC mill is the same as that for a conventional one explained above in that it goes backwards from the final pass to the first. However, taking advantage of the large crown control capacity of the mill to be free from the limitation of rolling load to keep plate crown constant, the reduction at each pass is in-

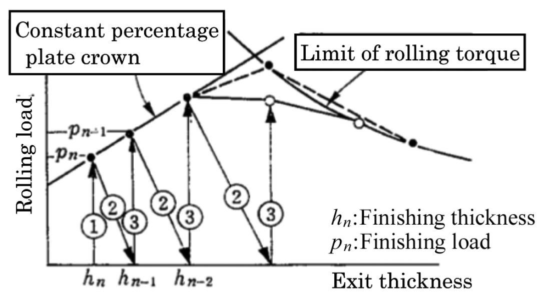

Fig. 4 Conceptual diagram of pass schedule setting[3]

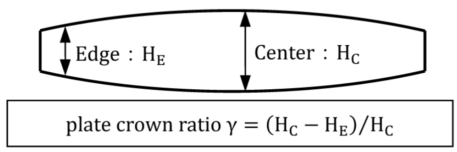

Fig. 5 Definition of the plate crown ratio

creased and the number of passes is smaller. **Figure 7** compares the pass schedules before and after the introduction of the PC mill; the number of passes has been decreased by two to three for each slab. This has significantly improved productivity, and in addition, made it possible to roll thin gauge plates stably owing to the lower temperature drop.

Heavy-reduction rolling is also effective at improving product quality. **Figure 8** shows the effect of the reduction ratio on the strength–toughness balance of steel plates for API X80 sour-resistant line pipes; tensile strength and low-temperature toughness have been improved by increasing the reduction at each pass from 10% to 20%.

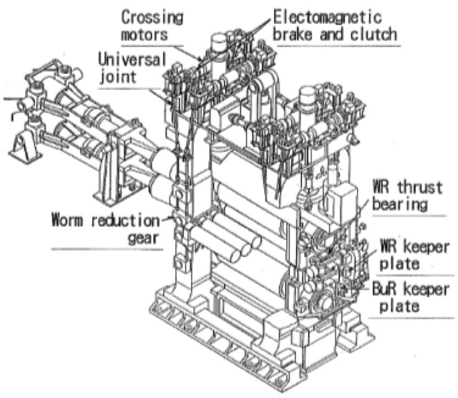

Fig. 6 General view of PC mill

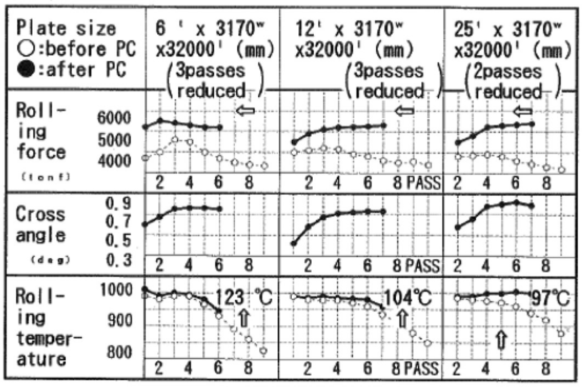

Fig. 7 Example of reduction in number of passes

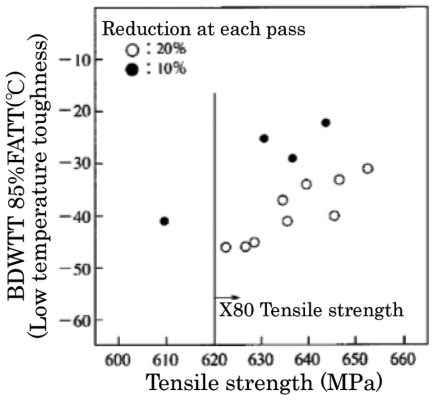

Fig. 8 Effects of heavy reduction on balance of strength and low temperature toughness (X80)

3.2 Yield improvement

As the steel cost of high-functionality plates is high as stated earlier, yield improvement is essential for cost reduction. Two important yield improvement measures peculiar, i.e., geometry control and edge bulging control, which are to plate products are presented below.

3.2.1 Planar shape control

Common rolling procedures for steel plates are given in **Fig. 9** [6]. The most characteristic feature of plate rolling is broad-side rolling with the slab turned by 90° on the roller table, and in this relation, control of plate width and planar shape is decisive for improving yield.

A technique called "draft alteration before turn (DAT)" [7] was introduced to the plate mills of Kimitsu and Oita Works; it is a method for controlling planar shape by applying thickness difference in the length direction by using automatic gauge control (AGC). More recently, for more accurate shape control, an attached edger has been installed at each of the plants.

The plate mills of Nagoya and Kashima Works use detached edgers for planar shape control; that of Kashima Plate Mill is a hydraulic edger capable of changing width reduction during a rolling pass. This is effective for short-stroke edger rolling to prevent head and tail narrowing or width shortage, which is likely to occur through conventional practice. The principle of the short-stroke edger practice is explained in **Fig. 10**. The narrowing at the head and tail is minimized by decreasing width reduction at the head and tail of a plate to increase production yield.[8, 9] **Figure 11** shows the yield improvement effect of short-stroke edger rolling. The yield has been improved owing to the less crop loss and edge trimming than by

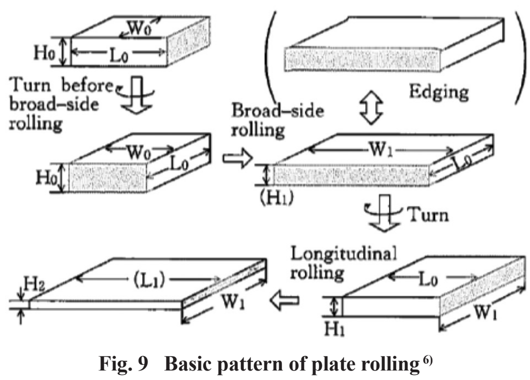

Fig. 9 Basic pattern of plate rolling [6]

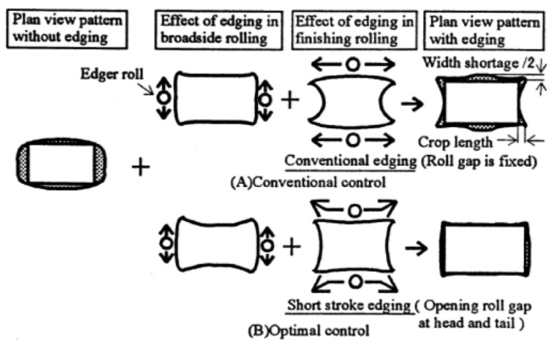

Fig. 10 Principle of short stroke edger [9]

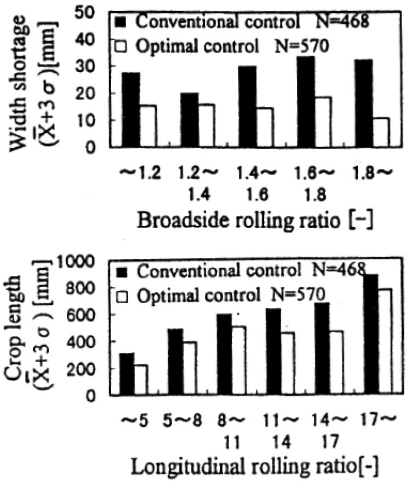

Fig. 11 Application example of short stroke edger [9]

conventional fixed edger pass rolling.

3.2.2 Estimation of edge bulging and its reduction

The number of rolling passes increases as steel strength increases, and bulging of plate edges as shown in **Fig. 12** (called double bulging) increases as the number of passes increases, leading to larger yield loss. Studies on bulging shape prediction models are being conducted to clarify the mechanism of its formation.[10–13] **Table 1** summarizes the growth of edge bulging during plate rolling. The bulging becomes larger as the product thickness increases and the reduction at each pass decreases; it is larger near the tail end at each pass. All these indicate that large double bulging occurs at the slab head and tail during broadside rolling, which is done while the slab is still thick. In particular, in rolling of high-functionality plates, the reduction in each pass tends to be small and the bulging is likely to be large as the hot deformation resistance of the steel is high.

An example of bulging shape obtained through FEM analysis is given in **Fig. 13**. The sectional shape can be approximated accurately using the following quartic equation:

$$y(x) = ax^4 + bx^2, \qquad (1)$$

where x is a dimensionless figure of the distance from the thickness center divided by a half of the plate thickness, y is the bulging at position x assuming that the bulging at the thickness center is 0, and a and b are coefficients, which can be obtained from δW_m, δW_s, and D_m in Fig. 13.

$$\begin{cases} a = \dfrac{\delta W_m D_m^2 - \delta W_m}{D_m^2 (1 - D_m^2)} \\ b = \dfrac{\delta W_m - D_m^4 \delta W_s}{D_m^2 (1 - D_m^2)} \end{cases} \qquad (2)$$

The above three parameters that define the bulging shape can be expressed using the following rolling parameter ψ:

$$\psi = \frac{\ell_d}{H_i} = \frac{\sqrt{R \cdot (H_i - H_o)}}{H_i} = \frac{\sqrt{R \cdot \Delta H}}{H_i} \qquad (3)$$

where ℓ_d is the contact arc length, H_i the entry plate thickness, H_o the exit plate thickness, ΔH the reduction, and R the work roll diameter.

Edge bulging shape per pass was estimated by FEM analysis changing rolling conditions, and the values of δW_m, δW_s, and D_m were determined for the bulging shape thus obtained. **Figure 14** shows their relationship with the rolling parameter ψ. Regression equations were formulated on the basis of the result of the above in the range of ψ from 0 to 1, and a formula for predicting the bulging shape has been worked out. A similar formula applicable to the bulging in the head and tail ends of a plate has also been worked out in the same manner.[11]

With a plate mill equipped with an edger stand, it is necessary to predict the bulging shape change due to edging (width reduction).[12]

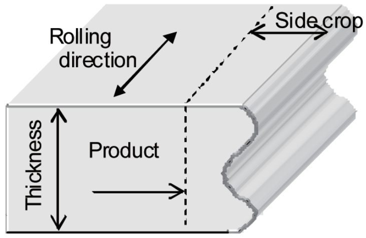

Fig. 12 Schematic diagram of double bulge shape [10]

Table 1 Influence of rolling conditions on bulging shape

Double bulge	Small → Large
Thickness	Thin → Thick
Reduction	Heavy → Light
WR Diameter	Large → Small
Deforming objects	Front → Edge → Tail

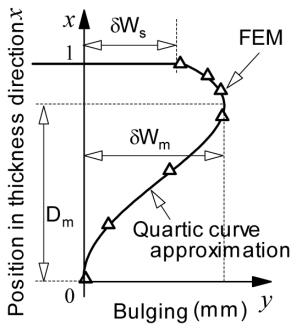

Fig. 13 Parameters to define bulge shape [10]

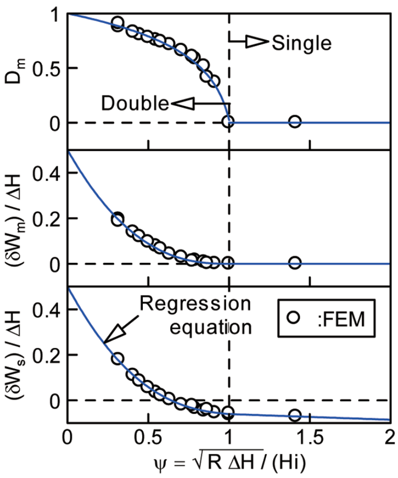

Fig. 14 Predictive equation of bulge shape by FEM analysis [10]

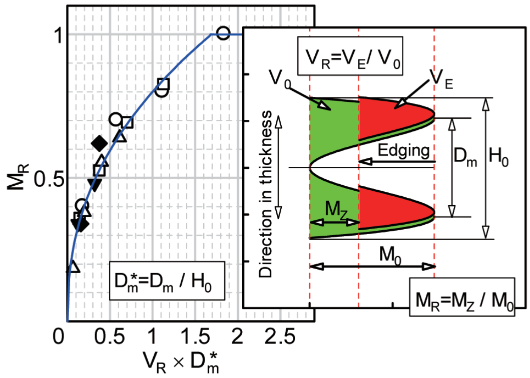

Fig. 15 Predictive equation for changes of bulge shape at edger rolling [12)]

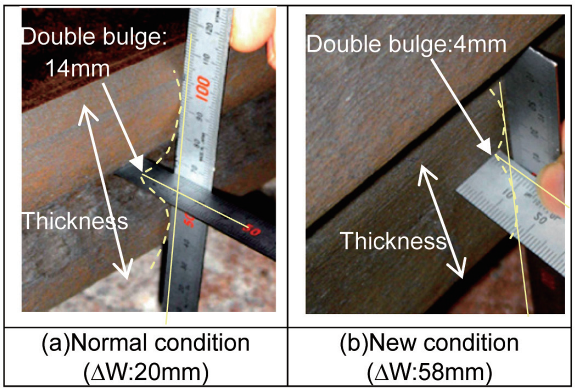

Fig. 16 Change of bulge shape under different edging conditions [13)]

Figure 15 shows the result of a laboratory test on the double bulge remaining after an edging pass; it is possible to express the size of bulging after edge rolling as a function of the ratio of sectional area reduction $V_R \times D_m$. It is clear from Fig 15 that even after an edging pass at a sectional area reduction ratio of 1.0 or a reduction equal to the formation of double bulging, the ratio of remaining bulges stays below 1.0. This indicates that to completely wipe out the double bulges by edging, a reduction 1.5 times the bulging or more must be applied.

As has been explained above, predicting the edge bulging shape after rolling passes became possible. To decrease the bulging by high-reduction edging, the prediction accuracy was verified through test rolling of hard steels with which the size of edge double bulging tends to be large (see **Fig. 16**). However, note that the planar geometry is affected by the change in the edge rolling condition to decrease the edge bulging, and it is necessary to find out an optimum rolling condition to obtain good planar geometry with edge bulging as small as possible, which is yet to be studied.

3.3 Manufacturing special-shape plates

Manufacturing plates of different dimensions in one piece is a recent commercial practice of plate rolling.[7)] This is done by combining products of different thicknesses or widths in a same slab to increase slab weight and raise productivity.

In shipbuilding and other industries, steel plates having two or three thicknesses lengthwise or gradually changing thickness (longitudinally profiled (LP) plates) are used to eliminate welding work or reduce structural weight. Longitudinally profiled plates are produced by gradually changing the mill screw down according to the desired taper. Nippon Steel & Sumitomo Metal can manufacture different types of such special-shape plates as given in **Fig. 17** [14)].

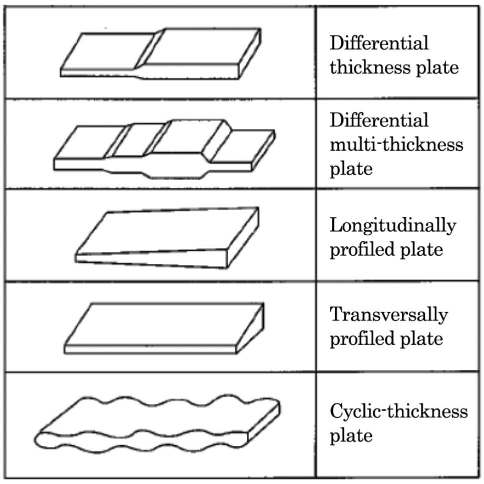

Fig. 17 Special-shape steel plates [14)]

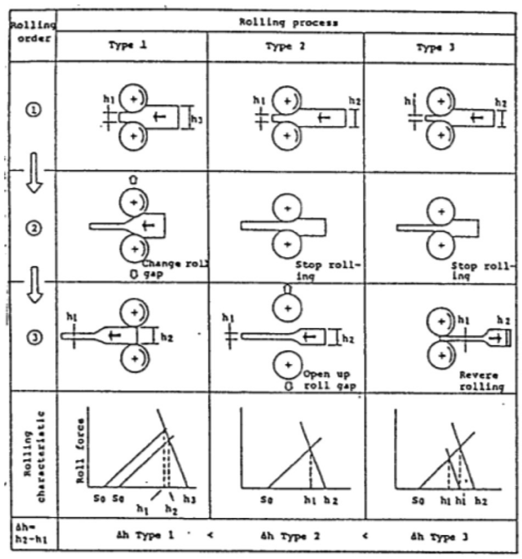

Fig. 18 Rolling patterns for twin-gauge plate [15)]

Figure 18 shows the methods of rolling differential-thickness plates.[15)] Different methods are employed depending on the thickness difference: type 1 is suitable when the difference is small, and types 2 and 3 are used as the difference increases. Longitudinally-profiled plates are rolled under tracking of longitudinal position of a plate and continuously changing the roll gap. Here, absolute gauge-meter AGC is instrumental in accurately obtaining desired taper shape in the longitudinal direction; it defines the plate thickness at the mill exit on the basis of the change in rolling load as the roll gap is changed.

When handling special-shape plates, small deviation in the plate positioning in the shearing process will lead to significant gauge error; for this reeason, these plates used to be gas-cut off line. Recently on-line cutting has been made practicable thanks to high-precision sensors such as laser thickness meters.

3.4 Schedule-free rolling

The width of plate products ranges from 1 to 5 m. To minimize the deterioration of plate crown and flatness caused by work roll

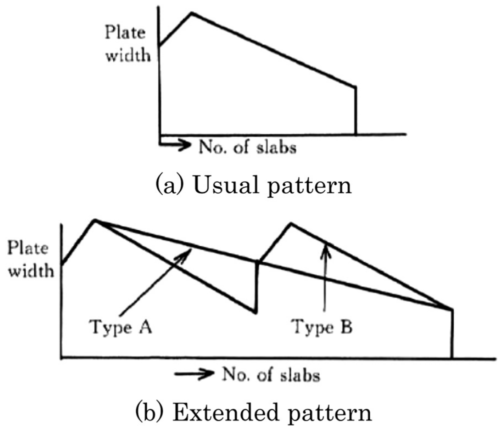

Fig. 19 Change of rolling width patterns

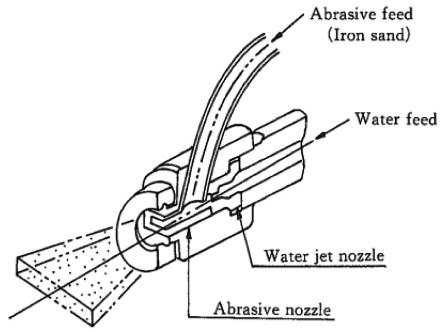

Fig. 20 Abrasive nozzle

profile change due to its wear and heat crown, plates are rolled in a one-roll campaign in descending order of width; this rolling order is known as a coffin pattern. However, high-functionality plates are often ordered in small lots, their reheating temperature is different from that of ordinary products, and they often require slow cooling after rolling. If they are to be rolled according to the coffin pattern, they will hinder smooth production and energy saving: the tonnage per roll campaign may decrease, and the charging temperature of hot-charge slabs to the reheating furnaces lowers because of waiting for their roll chance. Considering such problems, measures for schedule-free rolling without the width restriction have been developed and introduced (see **Fig. 19**).

An on-line roll dressing system using abrasive jet was developed at Kashima Works,[16] which made schedule-free rolling viable. The method consists of spraying abrasive powder with high-pressure water onto the work roll surface. The spray nozzle developed for the system is shown in **Fig. 20**; to prevent the piping from clogging, the water and the abrasive powder are fed via separate routes, and mixed immediately before being sprayed.

Figure 21 shows an example of roll profile improvement by the roll dressing system fitted to the plate finishing mill of Kashima Works. The dressing is applied to smooth out surface unevenness in predicted roll wear profile, and at actual profile measurement after rolling operation, the roll surfaces were found to be substantially free of unevenness. Thus the system proved effective at expanding roll chances, reducing the frequency of work roll changes to a half, and raising the working rate of the mill.

An on-line roll grinder (ORG) system has been introduced to the plate mill of Oita Works to remove the local wear of work rolls due

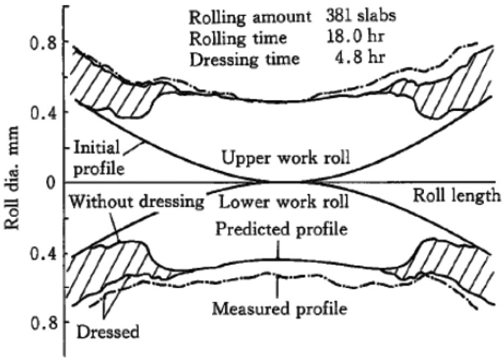

Fig. 21 Example of roll profile improvement

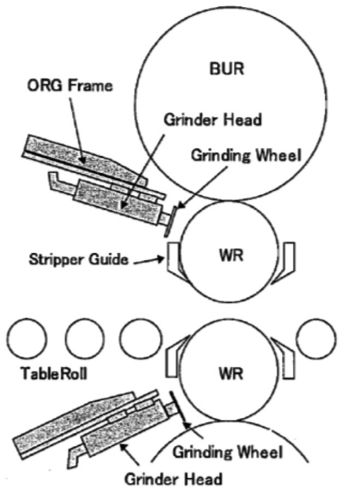

Fig. 22 Schematic view of ORG [17]

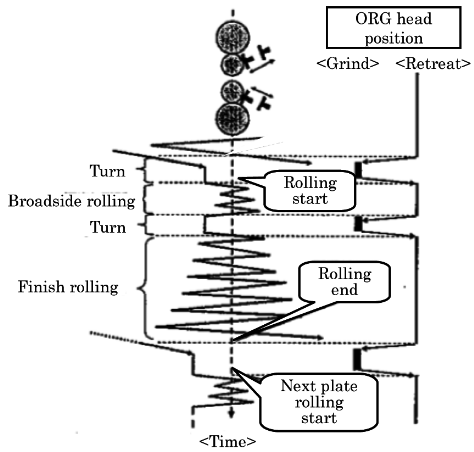

Fig. 23 Grinding timing of ORG

to rolling of plate edges.[17] **Figure 22** [17] schematically illustrates the ORG system. Two grinder heads mounted on a frame on the downstream side of the mill housing are provided for each work roll; flat-disc grinding wheels are selected for long service life. In plate rolling, short rolling passes succeed one after the other at short intervals, and grinding between passes is difficult; therefore, the rolls are ground during the interval between slabs or during the slab turn after broadside rolling (see **Fig. 23**).

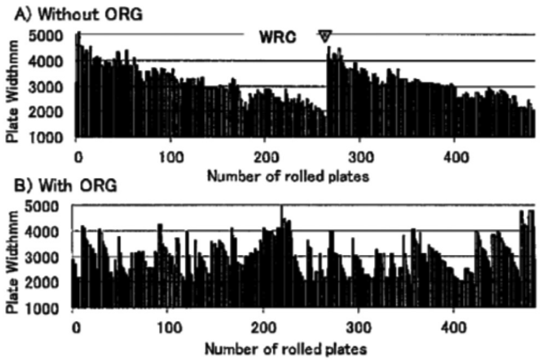

Fig. 24 Rolling schedule change with ORG

Figure 24 compares the rolling schedules before and after the introduction of the ORG system; the roll profile maintenance by ORG has enabled schedule-free rolling. The rolling tonnage between work roll changes has been increased from 2500 to 10000 t; consequently, the mill working ratio has been increased, the unit consumption of work rolls decreased, and the charging temperature of hot-charge slabs raised.

4. Thermo-mechanical Control Process (TMCP)

The thermo-mechanical control process (TMCP) to control heating, rolling, and cooling of steel on line to improve strength, toughness, weldability, and other property items is widely practiced in steel plate production. Many of the fundamental technologies of the TMCP were developed in Japan; the forerunners of Nippon Steel & Sumitomo Metal developed many such technologies by themselves. A process named the Sumitomo High Toughness (SHT) Process [18] was introduced to Kashima Works in 1975. It was unique in that desired material structure was obtained during plate rolling by cooling to below a transformation point and then reheating to prescribed temperature. However, because it involved additional steps to heat and roll the plates for a second time, it was inconvenient for production increase, and it is not practiced today.

Another technology to control material structure by on-line accelerated cooling alone was developed, and accordingly an on-line direct quenching (DQ) facility was installed at Kashima Plate Mill Plant in 1979. Then, what would become the prototypes of the present accelerated cooling equipment were constructed at Kashima and Kimitsu Works in 1983. The inventor companies named their respective processes differently; the process of Kimitsu was called the Continuous on-Line Control (CLC) Process, and that of Kashima was called the Dynamic Accelerated Cooling (DAC) Process.

The CLC process is characterized by hot leveling and cooling plates under restriction. A new type of cooling nozzle was developed in 2005 as an improvement to the CLC, which enabled homogeneous cooling even at low cooling rates; then, a new cooling facility capable of homogeneous cooling across a wide range of cooling rate, named the CLC-μ,[19] was installed at Kimitsu (see **Fig. 25**).

Likewise, DAC was also improved; in 2010, the then Sumitomo Metal Industries combined a high-precision cooling model of its own development [20, 21] with MULPIC, European equipment for accelerated cooling used at many plate mills worldwide, and constructed a new cooling system called DAC-n (see **Fig. 26**) to realize homogeneous cooling and enhanced accuracy of the cooling-end temperature.

Both these facilities have been instrumental in stably manufacturing high-end products such as the plates for super-high-strength line pipes of API X100 or higher grades, those for sour-resistant, thick-wall line pipes, off-shore structures, penstocks, and high-Ni plates for LNG tanks.

Fig. 25 Equipment of CLC-μ

Fig. 26 Equipment of DAC-n

5. Cold Levelling

As the fabrication of steel structures was automated and the need for cost reduction increased, higher shape quality came to be required for steel plates. In addition, the TMCP mentioned in the previous section increased the risk of disturbing flatness of plate products. Considering the situation, cold levelers each having a loading force of 5000 t were installed at Kimitsu and Nagoya Plate Mill Plants, and then in 2012, another of 7000 t at Kashima.

Meanwhile, a unique leveler was installed at Oita. This one, named the Oita Plate Leveler (OPL),[22, 23] is like a cluster-type rolling mill rather than a plate leveler, and corrects waviness of plates by applying a light reduction of approximately 0.2% instead of a bending force. During operation, it detects the waviness of the plate in the roll bite from the load distribution in the width direction and corrects it, if necessary; because of this ability, the OPL is called an intelligent mill. Each of the upper and the lower work roll is supported by two back-up rolls (BUR), each divided into short sections in the plate width direction, and the BUR sections cover the whole barrel length of the work roll from the entry and the delivery side in a staggered manner; in the case of the OPL, there are nine BUR sections on the entry side and ten on the delivery side supporting each of the upper and lower work roll at a cluster angle of 41°. Each of the BUR sections is equipped with a load cell to detect the load from the work roll independently, and all their measurements are combined to compose load distribution in the width direction. Then, to correct the waviness based on the load distribution, the position of each BUR section is controlled by an independent screw-down mechanism.

In summary, the OPL (1) measures the load distribution between the work rolls and the BUR sections using load cells, (2) estimates the transverse distribution of the load between the plate and the work rolls from the readings of the load cells, and (3) controls the positions of the BUR sections during processing such that the transverse load distribution becomes even.

6. Production Scheduling

To maintain a production quantity, secure a reasonable profit margin, and expand the share in the steel plate market under oversupply from countries such as China, it is now imperative for Japanese steelmakers to strengthen not only cost competitiveness but also non-cost competitiveness, which includes higher product performance and functionality to meet customer requirements, ability to propose solutions covering up to the final use of the products and delivery capacity (short delivery and shipment-ready ratio). The measures taken to enhance delivery capacity are explained below.

As a matter of policy, Nippon Steel & Sumitomo Metal covers, all the plate market sectors from general-purpose to high-end products. Consequently, the ratio of products that require finishing after rolling is increasing, and the bottleneck process in the plate mill plant changes from time to time depending on the product mix. To maintain high shipment-ready ratio and minimize the opportunity loss of every production facility (or maximize marginal profit), the Company has developed various techniques to optimize input for quarterly and monthly production plans and breaking them down into weekly and daily schedules.

6.1 Development of production time prediction [24)]

The production time of each plate order depends on the pattern of necessary finishing processes. Considering this, to define the process route pattern of each order, decision trees have been composed on the basis of past operation data (see **Fig. 27**). A model to estimate the production time for a process route pattern (i) (mean processing time $\tilde{\mu}_i$ and its standard deviation $\tilde{\sigma}_i$) has been formulated combining the decision trees and the processing time parameters for each process (j) (mean processing time μ_j and its standard deviation σ_j), which are derived also from past operation data (see **Fig. 28** and equation (4)). Work tools have been provided to support the people responsible for order input. All these in combination made it possible to optimally input orders to the quarterly and monthly production plans, maintain the shipment-ready ratio high, and shorten the average production time of orders by one to three days.

$$\tilde{\mu}_i = \sum_j p_{ij}\,\mu_j, \quad \tilde{\sigma}_i^2 = \sum_j p_{ij}\,\sigma_j^2 \tag{4}$$

P_{ij} : if or not process route pattern i includes finishing process j
μ_j : mean processing time at process j
σ_j : standard deviation of processing time at process j

6.2 Development of optimum converter-caster scheduling [25)]

Customers' orders compiled in the above manner into quarterly and monthly production plans avoiding bottlenecking are then broken down into weekly and daily rolling and processing schedules without bottlenecking. A method has been developed also for tapping/casting scheduling to maximize the number of sequential heats (lot) of a steel grade in consideration of the plate production schedule. Tapping/casting tonnage for each lot defined by steel grade and plate processing pattern is set by mixed integer programing so as to minimize the evaluation index (equation (5)) covering the number of sequential heats of the converter, the tapping/casting deadline date, and even loading of plate finishing processes under the conditions of equipment capacity and other restrictions.

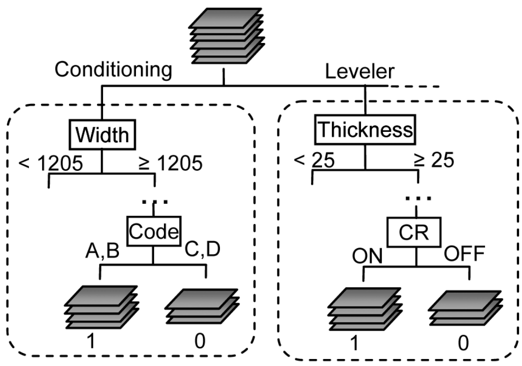

Fig. 27 Decision trees for process flow prediction

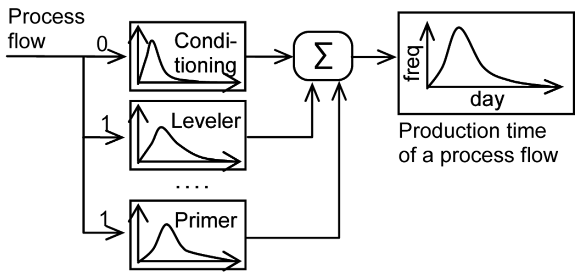

Fig. 28 Production time prediction diagram

Table 2 System performance (human plan: 100%)

Order quantity	Charge/Lot	Delay in casting	Excess load amount
Normal case	120%	32%	0.2%
Busy case	114%	75%	0.2%

[Optimization problem]

Evaluation function $J = W_1 J_1 + W_2 J_2 + W_3 J_3$ (5)

$J_1 = \Sigma_i \Sigma_t \delta_{i,t}$: number of steel grade changes at casting
$J_2 = \Sigma_j \Sigma_p \,|\, \Sigma_{t=0}^{p} \hat{x}_{j,t} - \Sigma_{t=0}^{p} X_{j,t} \,|$: late delivery
$J_3 = \Sigma_k \Sigma_t \,|\, \hat{y}_{k,t} - y_{k,t} \,|$: overflow exceeding capacity of plate finishing processes
W_1, W_2, W_3 : weighting factors
$\hat{x}_{j,t}$: amount of order j on tapping/casting date t
$x_{j,t}$: amount actually tapped for order j on tapping/casting deadline date t
$\delta_{i,t}$: if or not steel grade i is tapped on tapping/casting deadline date (0 or 1)
$y_{k,t} = \Sigma_j f_k(\cdot)\, x_{j,t}$: amount of processing at finishing process k on tapping/casting date t
$f_k(\cdot)$: function to estimate the processing rate at process k based on product specifications
Formulae of restrictions in converters, casters, processing yard areas, etc. are given.

As a result of the above scheduling method, in the case of normal order input, the loading of plate finishing processes have been smoothed, charge/lot has been increased by 20% and tapping/casting after the deadline date has been reduced to 32% (see **Table 2**).

7. Enhanced Quality Control

Quality identification in producing plates of widely varied speci-

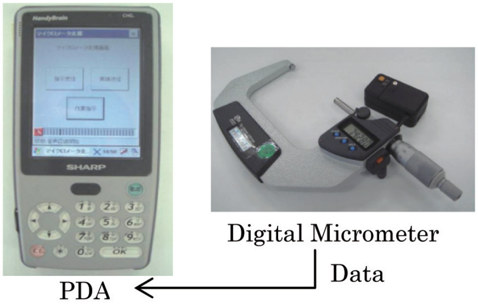

Fig. 29 PDA and digital micrometer

fications and sizes and correctly assign them to individual orders is essential for securing customers' confidence. Requirements of customers are becoming increasingly varied as stated earlier. On the other hand, because of the generation change of employees at production plants, difficulty in quality identification is increasing. In consideration of the situation, a quality identification control system has been constructed based on information communication technology (ICT) to improve customers' confidence and productivity of the plate finishing processing.[26] The ICT employed here features digital micrometers, data transmission terminals, and speech recognition devices based on a personal digital assistance (PDA) system (see **Fig. 29**).

The introduced quality identification control system assures reliable work structure of quality identification and has reduced the time for plate finishing processing to half of what it was in the past.

8. Closing

As described, advances of different production and control technologies have enabled manufacturing high-functionality plate products for various applications. In addition to the efforts to produce high-end products smoothly, stably, and at lower costs, it is necessary for us to bend efforts on technical development to offer plate products of higher grades combining multiple functionalities such as sour-resistant X80 plates and those for high-heat-input welding excellent in low-temperature toughness.

The principal subjects to attain this end include:

(1) Further advance of the TMCP technology to ensure good flatness stably in slow to rapid cooling,
(2) Incorporation of desired material quality in products through vertically integrated processes from steelmaking—casting of slabs excellent in surface and internal quality,
(3) New technologies to enable manufacturing high-functionality steel plates at lower costs (high-precision rolling, uniform cooling, etc. to attain an extreme in product yield), and
(4) Optimum production control system to deliver products to customers in a timely manner.

None of these is achievable in a short period, but we shall continue bending efforts to accelerate technical breakthroughs to better respond to customers' requests making the most of the technology that has been accumulated.

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