Technical Report

UDC 669 . 14 . 018 . 292 : 621 . 771 . 23 : 621 . 785

Plate Cooling Technology for the Thermo Mechanical Control Process (TMCP) in Nippon Steel & Sumitomo Metal Corporation

Yoshihiro SERIZAWA* Shigemasa NAKAGAWA
Yasunori KADOYA Ryuji YAMAMOTO
Hironori UENO Yoichi HARAGUCHI
Hisayoshi TACHIBANA Taisuke IWAKI
Tomoya ODA

Abstract

The plate cooling technology, which comprises of an essential part of TMCP, was initiated by installing the innovative cooling system in 1980. In this article, the accelerated cooling equipment and the cooling control system, which have been developed to meet the demand of both the advanced and uniform steel mechanical characteristics from the user, are described. The cooling equipment has been developed on the unvarying basic concept of the wide range of cooling rate and then undergone the fundamental redesigning of water spay, achieving highly homogeneous cooling. For the cooling control system, the precision temperature calculation system has been established based on the empirical data. And the advanced learning control scheme has been developed to reduce the inter-plate temperature fluctuation significantly.

1. Introduction

In the cooling technology for TMCP introduced in the 1980s for the production of highly functional heavy plates, uniform cooling of heavy plates 5 m wide, several ten meters long and 6–100 mm thick is sought after. Water is used as the cooling medium and as described later, water boils in various manners as the temperature of the steel plate is very high. For this reason, cooling equipment and cooling control technology, which are capable of controlling the uniformity of cooling in the width direction and on the top and bottom of a steel plate, are required, wherein the following factors must be considered: the influence of the cooling water flow, boiling mode of the cooling water, which that varies depending on the steel plate temperature, and other disturbances like surface characteristics of the steel plate. This article reports the cooling control technology uniquely developed by Nippon Steel & Sumitomo Metal Corporation.

2. Construction of Cooling Equipment

Table 1 shows the start-up years of cooling equipment introduced to plate mills in the world and major characteristics of the cooling equipment construction. **Figure 1** shows an example of construction.[1–3] Note that recently in China, as many as seven cooling equipments developed uniquely by the Chinese companies.[2] The differences in the construction among cooling equipments are due to the differences in the major specification of the plate-flattening hot leveler, such as position, number, plate-traveling-cooling type or plate-stationary-cooling, and presence or absence of pinch rolls that hold a steel plate in between.

2.1 Trend in hot leveler position

Good flatness of a steel pate is desired as upon cooling, flatness influences the distance for the water to collide with the steel plate and influences the flow of water on the steel plate. The function of the hot leveler (HL) installed before cooling equipment is to flatten the steel plate before cooling. On the other hand, the hot leveler installed after cooling equipment is intended to flatten the plate to rectify the shape deteriorated by cooling for easy transfer to subsequent process.

However, in case a steel plate is flattened right after cooling, allowing the existence of uneven temperature distribution within the steel plate, there is a possibility of the steel plate being distorted due to larger contraction of the part at a higher temperature and less contraction of the part at a lower temperature when the temperature drops to room temperature. Therefore, it is considered that flattening right after cooling is not desirable. **Figure 2** shows the chronologi-

* Senior Researcher, Ph.D, Process Technology Div., Process Research Laboratories
20-1 Shintomi, Futtsu City, Chiba Pref. 293-8511

Table 1 Specification of cooling equipments of the plate mill in the world

Country	Company mill		Start up	Location of HL (before, after, both side of ACC)	ACC pinching roll	Length (m)	Nozzle: Top side	Nozzle: Bottom side	Direct quench availability
Japan	NSSMC	A	1984	Before	○	21	1st part: Slit jet 2nd part: Spray	1st part: Slit jet 2nd part: Spray	○
			2012						
		B	1983	Before	○	20	1st part: Slit jet 2nd part: Spray	1st part: Slit jet 2nd part: Spray	○
			2005						
		C	1986	Before	○	21	1st part: Slit jet 2nd part: Spray	1st part: Slit jet 2nd part: Spray	○
			2009						
		D	1983	After		27	Slit laminar	Spray	
			1979	After		14	Spray	Spray	○
			2010	Both		24	Multi jet	Multi jet	○
	A	A	1983	Both		39	Laminar	Spray	
			1985	Both		22	Slit jet + Laminer	Slit jet + Spray	○
	B	A	1985	After	○	20	Laminar	Close suction laminer	○
			2004	Both	○	20	Corridor flow	Close suction laminer	○
		B	1983	After		40	Rord-like nozzle	Dish-like jet	
			1983	After	○	13	Immerssion + Stir	Immerssion + Stir	○
			2003	Both	○	12	Corridor flow	Close suction laminer	○
		C	1980	After		44	Laminar	Spray	
			1998	Both	○	20	Corridor flow	Close suction laminer	○
Europe	C	A	1986	After		30	Pipe	Pipe	○
	D	A	1984	After		12	Pipe	Pipe	○
	E	A	1984	After		12	Laminar	Laminar	○
U.S.A.	F	A	1995	Both			Mist	Mist	○
Taiwan	G	A	1994	Both		24	Laminar jet	Laminar jet	
Korea	H	A	1989	After		30	Mist + Pipe	Mist + Pipe	○
			2003	Both		24	Pipe	Pipe	○
China	I-O	A-G	2010	Both		24	1st part: Slit jet 2nd part: Spray	1st part: Slit jet 2nd part: Spray	○

ACC: Accelerated cooling

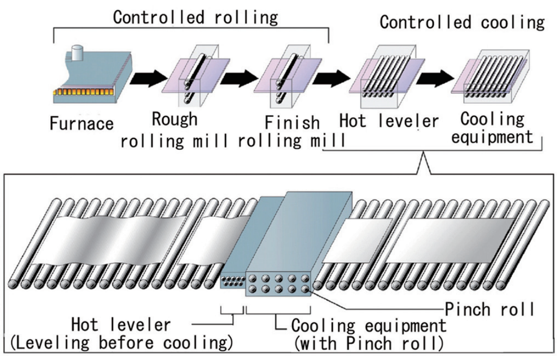

Fig. 1 Cooling equipment in the plate rolling mill

cal transition of hot leveler position based on the year of installation. As the figure shows, in many cases in early years, a hot leveler was installed after the cooling equipment. It is considered that the steel plate formed after cooling was bad in the early TMCP technology, yielding higher rate of flatness rectification. On the other hand, however, hot levelers installed before the cooling equipment have grown larger in number since after 1995, and installation in such a manner including the case of installing a hot leveler simultaneously after cooling equipment has become mainstream. In Nippon Steel &

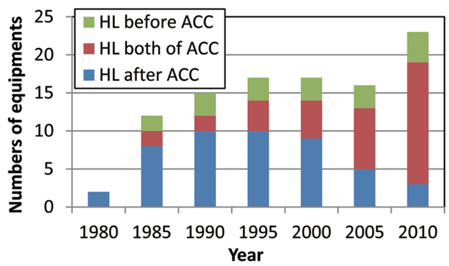

Fig. 2 Transition of the number of cooling equipment classified by the hot leveler position

Sumitomo Metal, hot levelers are installed before the cooling equipment based on the concept that the improved flatness of a steel plate before cooling serves uniform cooling.

2.2 Trend in pinch roll installation

Pinch rolls of cooling equipment have the function of holding a steel plate in between, promoting uniform cooling by suppressing the plate deformation during cooling, improving plate form, and securing cooling zones. In cooling steel plates, finish cooling temperature and cooling time vary greatly depending on the size and the aimed material. Therefore, it becomes necessary to adjust the length of the cooling zone of the cooling equipment. The pinch rolls deter

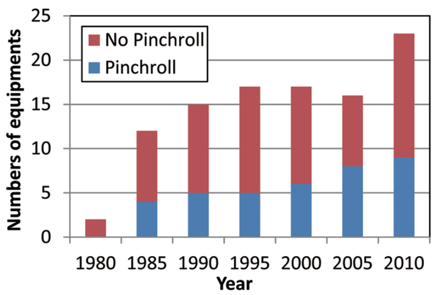

Fig. 3 Transition of the number of cooling equipment with or without the pinch rolls

the cooling water flow to downstream of the cooling zone, preventing non-uniform cooling due to sojourning water on the steel plate outside the cooling zone, thereby separating the cooling zone from non-cooling zone. **Figure 3** shows the chronological transition of the number of cooling equipment equipped with pinch rolls. As Fig. 3 shows, the number of cooling equipment equipped with pinch rolls is increasing. In Nippon Steel & Sumitomo Metal, except the one in Kashima Works, pinch rolls have been installed in all cooling equipments at the time of commissioning, a function now growing to a global standard of late.

3. Boiling Phenomenon of Accelerated Cooling and Its Subject

Unlike the boiling behavior observed in our daily lives, the cooling capacity of water in the case of cooling a steel plate at high temperature shows a characteristic behavior as expressed by what is termed as boiling curve[4] in **Fig. 4**. In the high temperature region, a steam vapor film exists between the steel plate and the water, causing a state termed as film boiling and, despite high temperature in the region, the cooling capacity becomes slightly lower. As the steel plate temperature goes down, contacting of water with the steel plate starts and, as the steel plate temperature further goes down, the area of contact of water with the steel plate expands and the state of cooling enters the transition boiling region where the cooling capacity increases. As the temperature of the plate further goes down, the state of cooling goes into the nucleate boiling region where bubbles generated play a major role. In cooling steel plates, cooling in the transition boiling region is crucial. In this region, as the cooling capacity increases along with the decrease in plate temperature, uneven temperature distribution within a steel plate developed in the earlier cooling is enlarged and, finish cooling temperature also varies for each steel plate. Along with the growing sophistication of material in recent years, materials requiring termination of cooling in the transition boiling region have increased and accordingly, adverse effects on production due to increased post-cooling treatment have increased. For this reason, needs for improving the cooling uniformity and sophistication of cooling control increased, and second-generation cooling equipments have been installed since after 2000.

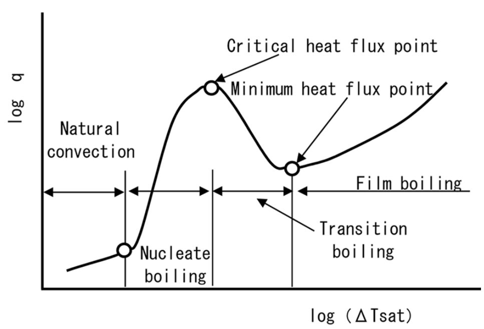

Fig. 4 Boiling curve of water

4. Development of Cooling Equipment

4.1 Verification of performance based on real-size test equipment

A cooling equipment is equipped with a group of pinch rolls installed on the top and bottom of a steel plate, holding the plate in between and cooling it from the top and bottom with water having a flow rate as high as 1–2 $m^3/m^2/min$. This flow rate reaches 8–16 $m^3/m^2/min$ per meter in case of a steel plate of 4 m in width, which is equivalent to a flow rate large enough to fill in 40–80 steel drum containers per minute. A cooling equipment is also equipped with many spray nozzles because it needs a high water flow rate as the maximum width is becoming 5 m. The function required for such a cooling equipment is the wide ranged cooling ability, this function enables the equipment manufacture various kinds of steel and the cooling uniformity in the plate.

In the development, it is difficult to guarantee the performance of an actual large scale equipment by simply conducting a small-scale experiment. Therefore, as shown in **Fig. 5**, an equipment simulating an actual equipment and a water spraying header to be used actually were built for experimental purpose, and water spraying performance verification tests and uniform cooling performance verification tests were conducted. As for the header water spraying function, the water flow rate was changed from a low flow rate to a high flow rate and the distribution in the width direction was measured. Its result is shown in **Fig. 6**. As the figure shows, the distribution was good, being controlled within ±2%. The cooling test was executed by inserting heated test pieces at several locations on the width direction while spraying water.

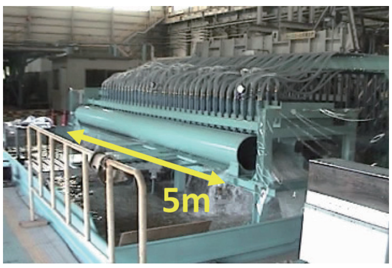

Fig. 5 Photograph of real-size test equipment

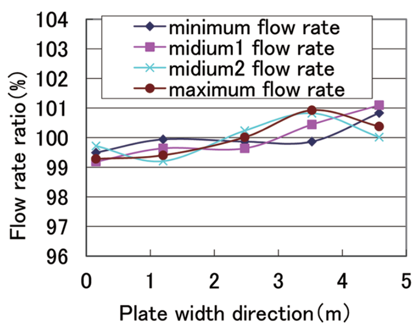

Fig. 6 Flow rate distribution of water header of cooling equipment in the plate width direction

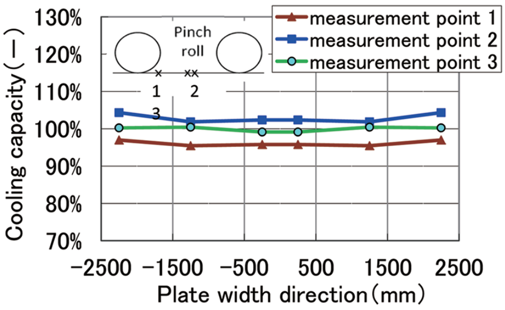

Fig. 7 Cooling capacity distribution of cooling equipment

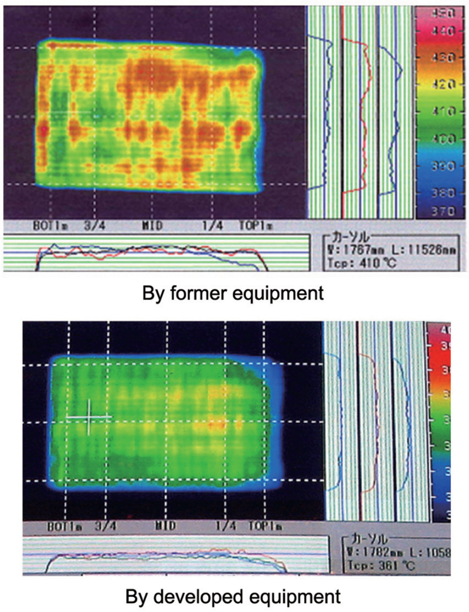

Fig. 8 Temperature distribution after cooling

In the cooling test, the cooling capacity at the center position of respective test piece placed at six locations on the width direction and at three locations between pinch rolls was measured. **Figure 7** shows the cooling capacity at each location on the width direction divided by the average value. As Fig. 7 shows, the cooling capacity of the developed equipment displays high uniformity with a difference of 1–2% in the width direction. Furthermore, it was found that even at the location adjacent to a roll, high cooling capacity of 95% of the one in the center location between the rolls was achieved.

4.2 Effect of remodeling of real cooling equipment

Figure 8 shows the result of the operation of a cooling equipment wherein the performance was verified on the basis of the result of the experiment conducted on a small scale and on a large scale.[3] The temperature deviation after cooling within a plate after development was reduced to 30°C, almost half as compared with 50°C before development and great improvement in uniformity in cooling was confirmed.

5. Plate Temperature Prediction Model in Cooling

In the plate temperature prediction in cooling, the finish cooling temperature (temperature at the delivery side) is predicted based on the start cooling temperature (the measured temperature at the entry side) using a steel plate temperature prediction model wherein the position of the pyrometer on the entry side of the cooling equipment is taken as the starting point of prediction and the position of the pyrometer on the delivery side of the equipment is taken as the termination point.

5.1 Water-cooling heat transfer model for nozzle jet

Under a certain condition depending on the aimed quality of a steel plate, the finish cooling temperature may be set in somewhere in the transition boiling region. To produce steel plates of such specifications in a stable manner, it is necessary to establish a model of determining the heat transfer coefficient, taking into consideration the state of boiling and to enhance the accuracy of the steel plate temperature prediction by using the model so established. Then, the cooling behavior on a steel plate was formularized by conducting the analysis of the jet ejected from a nozzle of a cooling equipment shown in **Fig. 9**[5, 6] and the laboratory experiments of the cooling[7] as shown in **Fig. 10**, and a water-cooling heat transfer model with boiling conditions taken into consideration has been developed.

In the off-line precise analysis model (numerical fluid analysis), the state of fluidity of cooling water composed of jet and residual water was analyzed by using numerical analysis of gas-liquid-mixed phase flow. The distribution of the water-cooling heat transfer coefficient was precisely calculated by using the temperature and the flow velocity of the cooling water thus obtained and the steel plate surface temperature. Such analysis was conducted by changing the cooling conditions such as water temperature and jet velocity, and by equalizing the obtained distribution of the heat transfer on the steel surface, a boiling curve corresponding to respective cooling condition was obtained. On the basis of the above result of numerical analysis and the result of the cooling experiment, a water-cooling heat transfer model for on-line control was developed.

In this model, the cooling phenomenon of a single jet was focused on. The fluid state is analyzed; assuming that, as **Fig. 11** shows, the cooling water jet coming out of a nozzle collides with a steel plate and disperses radially and circularly. The area that a nozzle of a header covers is considered to be equal to the area of the diffusion circle, and the heat transfer model was developed in the following manner. The circle so formed is divided by several concentric circles (a section being formed by such circles is hereinafter

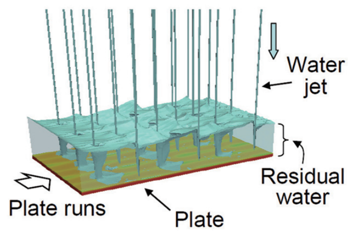

Fig. 9 Numerical analysis result of the nozzle jet and the residual water

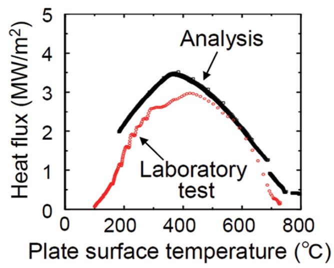

Fig. 10 Comparison between laboratory test result and analysis model result of cooling properties

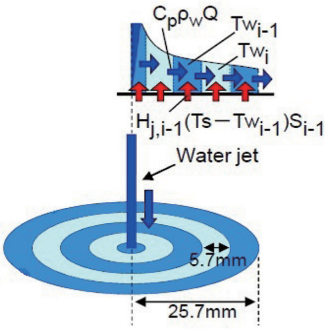

Fig. 11 Heat transfer model around the jet

called as cell). State of boiling (ratio of nucleate boiling), heat transfer coefficient, and cooling water temperature are calculated in succession along the flow in radial direction from the center cell to the utmost outer cell. In this calculation, the steel plate surface temperature of each cell in the diffusion circle is assumed to be same with others'. First, heat transfer coefficients in the nucleate boiling region and in the film boiling region were calculated independently based on the formula (2) and (3) lead from the aforementioned analytical study conforming to actual equipment cooling condition. The heat transfer coefficient of each cell is calculated by distributing the heat transfer coefficients in accordance with the nucleate boiling ratio in respective cell, using the formula (4).

Furthermore, it is assumed as shown in **Fig. 12** that in each cell, the heat released from the steel plate is uniformly absorbed by the over-passing cooling water, and the water temperature after passing a cell (temperature in the next outer cell) is calculated using the formula (1).

$$T_{Wi} = T_{Wi-1} + \frac{H_{j,\,i-1}\,(T_S - T_{Wi-1})\,S_{i-1}}{C_p \rho_w Q} \tag{1}$$

$$H_{Nj} = C_{Nj}\,P_r^{\,C_1} R_e^{\,C_2} S_b^{\,C_3} S_p^{\,C_4} \frac{\lambda_w\,(T_S - T_{sat})}{(T_S - T_{Wi})\,L_j} \tag{2}$$

$$H_{Fj} = C_{Fj}\,P_r R_e^{\,C_5} \frac{\lambda_w\,(T_{sat} - T_{Wi})}{(T_S - T_{Wi})\,L_j} \tag{3}$$

$$H_j = BH_{Nj} + (1-B)\,H_{Fj} \tag{4}$$

$$R_e = \frac{V_j L_j}{\nu} \tag{5}$$

$$S_b = \frac{C_p\,(T_{sat} - T_{Wi})}{h_{lv}} \tag{6}$$

$$S_p = \frac{C_{pv}\,(T_S - T_{sat})}{h_{lv}} \tag{7}$$

Where;
H: Heat transfer coefficient of cell
S: Area of a cell
C_p: Specific heat of water
C_{pv}: Specific heat of steam
ρ_w: Water density
Q: Water flow rate of nozzle
N: Subscript for nucleate boiling
F: Subscript for film boiling
i: Subscript for cell number
j: Subscript for cooling header section
P_r: Prandtl number of water

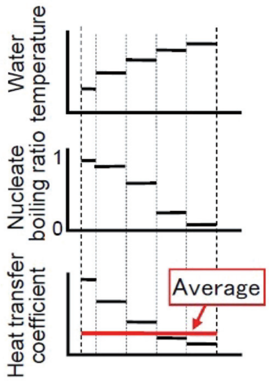

Fig. 12 Heat transfer model in cooling section

λ_w: Thermal conductivity of water
B: Nucleate boiling ratio
V_j: Diffusion velocity of cooling water
L_j: Representing length
T_{sat}: Saturated temperature of water
h_{lv}: Evaporation latent heat of water
C_{Nj}; C_{Fj}: Tuning parameters
$C_{1\sim5}$: Parameters determined by the laboratory experiment

From the above, the heat transfer coefficient is calculated for each cell as shown in Fig. 12. Then, the average heat transfer coefficient within a diffusion circle is calculated using these coefficients. Furthermore, this calculation is not made for all nozzles in the respective header but only for necessary temperature calculation points that include the center point in the width direction of a steel plate, thereby relieving the computational load. Moreover, the temperature calculation at the header cooling section is conducted by using the average heat transfer coefficient obtained at the temperature calculation points.

5.2 Water-cooling heat transfer model between cooling headers

The heat transfer model to be applied between cooling headers is a model developed by formularizing the phenomenon of the cooling water ejected by the header being discharged in the width direction of a steel plate. There are two points newly added to the heat transfer model in the cooling header section. One is to use the discharging velocity in the width direction formularized as a function of the plate width and the header water flow rate based on the aforementioned analytical study. Another is to use the temperature of the cooling water being discharged from the utmost outer cell of the diffusion circle calculated on the basis of the temperature of the water ejected from the header as the cooling water temperature. Furthermore, the lower side is less prone to be influenced by the cooling water; therefore, the heat transfer is treated as only via convection and radiation.

5.3 Results of temperature prediction with heat transfer model

A scatter diagram of the delivery side temperature (finish cooling temperature) calculated by using the proposed model optimized by adjusting parameters vs measured temperature (actual finish cooling temperature) is shown in **Fig. 13** wherein the result of the conventional model is also shown for comparison. Here, for the water-cooling heat transfer model of the conventional model, a model was used which executes with actual data correction-coefficient-learning of the nominal water-cooling heat transfer coefficient curve obtained from water-cooling experiment. From Fig. 13, it is found that when the proposed model is used, the calculation accuracy in the range of 200°C–450°C has been improved in particular as com-

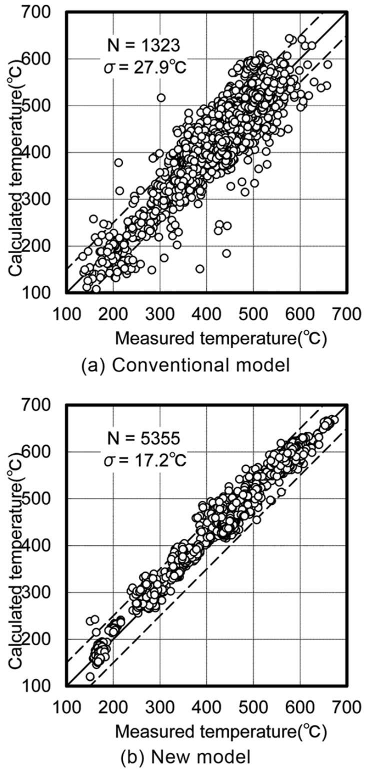

Fig. 13 Comparison between calculated and measured temperature of FCT

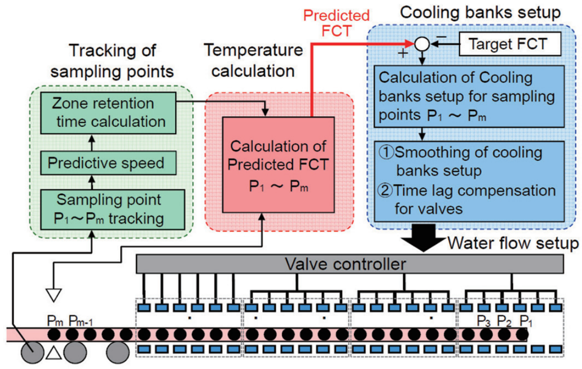

Fig. 14 Schematic diagram of dynamic control model

pared with that in the conventional model, and the accuracy in the low temperature region has been enhanced. Furthermore, the σ value of the proposed model is 17.2, smaller by 38% than the σ value of 27.9 of the conventional model, and a highly accurate prediction of the finish cooling temperature is possible.

6. Finish Cooling Temperature Control

The basic function of the finish cooling temperature control is to predict the steel plate temperature after cooling by using the steel plate temperature prediction model and to control the cooling equipment so that said predicted temperature agrees with the targeted temperature. To execute the function, the cooling control consists of such functions as preset control, dynamic control, and adaptive control. The respective functions are explained hereunder.

6.1 Preset control

Preset control has a control function that is actuated at the moment the head end of a steel plate reaches the entry side pyrometer and executes various initial settings for the cooling equipment before cooling of the steel plate starts. In the developed preset control, a control function that controls not only the finish cooling temperature but also the targeted cooling rate was developed. In the developed preset control, cooling time is calculated on the basis of the targeted finish cooling temperature and the targeted cooling rate, and then the steel plate transfer speed is determined. Subsequently is the cooling water flow rate determined on the basis of the predicted finish cooling temperature, using the steel plate temperature prediction model based on the water flow rate, so that the targeted finish cooling temperature is achieved. To determine the optimum transfer speed and cooling water flow rate, conversion calculation is conducted.

6.2 Dynamic control

In the cooling control of a steel plate, controlling the finish cooling temperature to the targeted temperature with high accuracy along the entire length of the steel plate is sought after. However, as a steel plate after rolling passes through a cooling equipment with temperature variations in its longitudinal direction and as the operated cooling device is installed in a separated manner in the direction of plate transfer, it is necessary to correctly grasp the position of the steel plate relative to the cooling equipment and to apply real-time setting of cooling equipment optimized to momentarily changing condition. In the cooling control of a continuously hot-rolled strip, because the strip is very long (several hundred meters–2000 m), dynamic control is executed that dynamically adjusts cooling water flow rate by determining positions of virtual control points on the strip, creating control points, conducting tracking of the control points, and conducting temperature tracking of the control points.[8–10] However, in the cooling control of heavy plates where the steel plate length is short (approximately several tens meters), the control method employed was not the control method wherein cooling water flow rate of a cooling equipment is dynamically controlled but the generally used control method wherein fine adjustment of the entering speed of a steel plate and the control of the speed of the steel plate during passage are made based on the actual temperature at the entry side of a cooling equipment.[11, 12]

In the control, to realize high uniformity of finish cooling temperature along the longitudinal direction, a dynamic control was developed in which the cooling water flow rate of a cooling equipment is dynamically adjusted, instead of the control method wherein steel plate traveling speed is adjusted during passage.

In the dynamic control of a developed cooling equipment, virtual control points were provided at a constant pitch (1 m pitch) on a steel plate and temperature prediction calculation was executed for these control points, determining cooling water flow rate of a cooling equipment so that the predicted finish cooling temperature becomes the targeted temperature, and tracking the positions of the control points precisely and setting cooling water flow rate for the control points (**Fig. 14**).

6.3 Adaptive control

Preset control and dynamic control execute control on the basis of the result of the prediction of a steel plate temperature and the prediction accuracy of the model influences the control accuracy. However, in the actual operations, as error factors exist where it is difficult for the steel plate temperature prediction model to predict temperature, it is difficult to achieve high accuracy with the prediction-based-control alone. Usually, in the learning of cooling control,

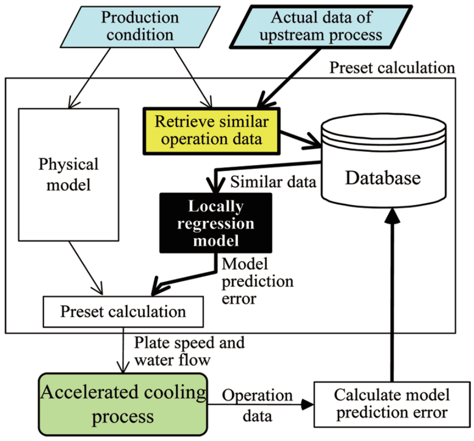

Fig. 15 Outline of proposed adaptation method

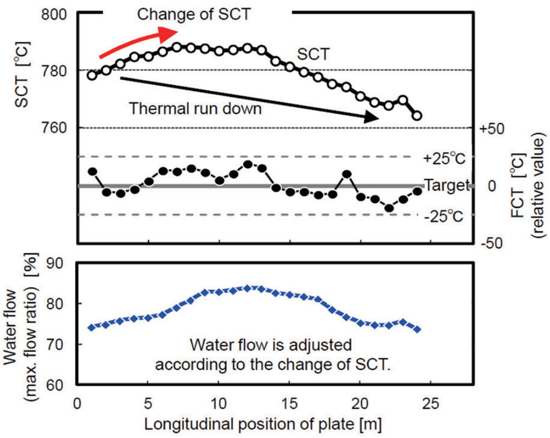

Fig. 17 Result of dynamic control (plate thickness 30 mm, FCT = 450)

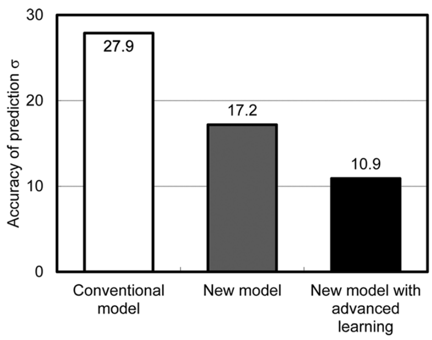

Fig. 16 Accuracy of prediction of finish cooling temperature

generally adopted is the method of parameter adaptation [13] of correction coefficient of heat transfer coefficient. However, in this adaptive control, the method of learning directly adopting errors caused by the prediction model was used and an advanced adaptation method which employs a database has been applied.[14]

In the method, as shown in **Fig. 15**, prediction errors of the steel plate temperature prediction model are calculated upon completion of steel plate cooling and they are stored in a data base together with the actual data of production condition and operation. And prior to the start of cooling of the next material, data of production condition and actual result in rolling process which are similar to the conditions of the next material are extracted from the data base and the prediction error is estimated with local regression analysis method using similar data. In the preset control and the dynamic control for the next material, the values targeted by the systems are bias-corrected by the amount of the error estimated as aforementioned. In this case, the model-error-adaptation is executed at the points set lengthwise in the overall length of the heavy steel plate to incorporate into the adaptive control the differences in errors of the model in the lengthwise direction of a heavy steel plate.

By applying the adaptive control, as shown in **Fig. 16**, the finish cooling temperature prediction accuracy has been further improved and finish cooling temperature control can be executed with high accuracy.

7. Result of Online Control

The developed cooling control model was applied to cooling control of a cooling equipment.

Figure 17 shows an example of the control result of the developed cooling control model. This example concerns a case of a steel plate of 30 mm in thickness with targeted finish cooling temperature of 450°C. This shows an example of control where cooling water flow rate at the head end part of the steel plate is set by preset control, and from the head-end part to the tail-end part, the cooling water flow rate is set continuously by dynamic control along the longitudinal direction of the steel plate. Though conventionally, start cooling temperature of a heavy plate gradually goes down from the head end towards the tail end by the thermal rundown phenomenon. In this case, however, the rise of start cooling temperature from the head end part to middle section due to operational disturbances is observed while start cooling temperature is going down from the middle section towards the tail-end part. Under such conditions, the dynamic control function increases cooling water flow rate of the on-line accelerated cooling equipment from the head end part to middle section and decreases cooling water flow rate. It is found that as a result thereof, finish cooling temperature along the entire length of the steel plate is controlled to within ±25°C of the targeted temperature (targeted finish cooling temperature = 450°C).

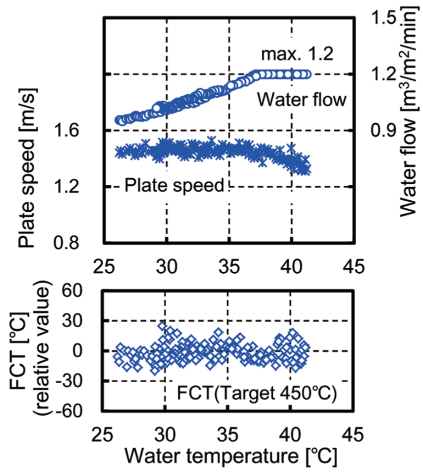

Fig. 18 Prediction error in the case of change of water temperature (plate thickness 30 mm, FCT = 450)

In **Fig. 18**, for 159 steel plates cooled in succession, as opposed to the cooling water temperature taken on the horizontal axis, cooling rates, plate speeds, and finish cooling temperature (the temperature at the point 4 m apart from the head end, being taken as the representative temperature) are shown. It is found that despite large variations in the cooling water temperature, errors of finish cooling temperature prediction lie approximately within ±20°C and furthermore, the finish cooling temperature is controlled to almost a targeted value by adjusting water flow rate and plate speed.

As mentioned above, even if the targeted finish cooling temperature is 450°C, which lies in the temperature region where cooling control has been once considered difficult, stable production has become possible owing to the application of the developed cooling control model.

8. Conclusion

As an outcome of the development of the cooling equipment and the control technology as mentioned above, transition of cooling processing ratio is shown in **Fig. 19**. During the past 17 years, the ratio of cooling processing has grown three times. Recently, approximately more than half of the production amount is cooling-processed, and the cooling equipment and the control technology are making great contribution to the production of high-function steel material and material quality uniformity. Hereafter as well, authors are determined to further pursue the improvement of the cooling control technology, wishing to contribute to society through production of steel plate.

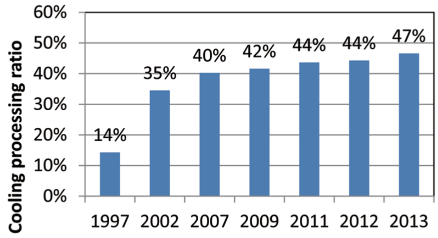

Fig. 19 Recent cooling processing ratio in NSSMC

References

1) Yazawa, T.: 207・208th Nishiyama Memorial Technical Course. 2007, p. 1
2) Bingxing, W. et al.: Rolling 2013. Venice, 2013, AIM (Associazione Italiana di Metallurgia)
3) Ueno, H.: Nippon Steel Monthly. 163 (11), 11 (2006)
4) The Japan Society of Mechanical Engineering: Heat Transfer in Boiling and Cooling. First Edition, Tokyo, Nihon Kogyo Shuppan, 1998, p. 8
5) Kobayashi, K. et al.: CAMP-ISIJ. 25, 1043 (2012)
6) Nakamura, O. et al.: CAMP-ISIJ. 25, 1044 (2012)
7) Haraguchi, Y. et al.: CAMP-ISIJ. 25, 1042 (2012)
8) Nakagawa, S. et.al.: Transactions of the Society of Instrument and Control Engineers. 45 (4), 233 (2009)
9) Takahashi, R.: Control Technology in Steel Industry. First Edition, Tokyo, Corona Publishing, 2002
10) Mihara, N. et al.: The Papers of Technical Meeting on Metal Industries Division, IEE Japan. 97 (11), 17 (1997)
11) Kuribayashi, T. et al.: CAMP-ISIJ. 3, 1369 (1990)
12) Takanawa, T. et al.: Sumitomo Metals. 38 (4), 406 (1986)
13) Tsukuda, T. et.al.: R&D Kobe Steel Engineering Reports. 61 (2), 75 (2011)
14) Kadoya, Y. et al.: Transactions of the Society of Instrument and Control Engineers. 50 (7), 528 (2014)


Yoshihiro SERIZAWA
Senior Researcher, Ph.D
Process Technology Div.
Process Research Laboratories
20-1 Shintomi, Futtsu City, Chiba Pref. 293-8511


Shigemasa NAKAGAWA
General Manager, Head of Dept., Dr.Eng
Systems & Control Engineering Dept.
Equipment Div.
Oita Works


Yasunori KADOYA
General Manager, Head of Dept.
Plant Control Development Dept.
Plant Engineering & Maintenance Div.
Kashima Works


Ryuji YAMAMOTO
Senior Manager
Plate Div.
Kimitsu Works


Hironori UENO
Senior Manager, Head of Mill
Plate Div.
Nagoya Works


Yoichi HARAGUCHI
Senior Manager
Plant Engineering & Maintenance Div.
Kashima Works


Hisayoshi TACHIBANA
Senior Manager
Plant Engineering & Maintenance Div.
Kashima Works


Taisuke IWAKI
Manager
Plant Engineering Div.
Plant Engineering and Facility Management Center


Tomoya ODA
Senior Manager
Plate Div.
Oita Works