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High-accuracy Profile Prediction Model for Mixed Scheduled Rolling of High Tensile Strength and Mild Steel in Hot Strip Finishing Mill

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Abstract

High accuracy online strip profile prediction model has been developed for realize mixed scheduled rolling of high tensile strength and mild steel in hot strip finishing mill. New method is based on matrix model. The force and tension distribution is considered by experiment and FEM analysis. First the force and tension distribution when there is no change in strip profile is calculated as the specified value, second the distribution when there is an actual change in strip profile is calculated as the variation from the specified value. Then the profile prediction accuracy of high tensile strength steel, whose rolling force is higher than that of mild steel, was improved. The model was applied to online crown, flatness, and walking control in hot strip finishing mill. As the result, mixed scheduled rolling of high tensile strength and mild steel was commercially promoted.

1. Introduction

In recent years, an improvement in fuel efficiency has been strongly demanded for automobiles as an environmental measure, and simultaneously, safety standards for collisions are becoming harsher. For these reasons, employment of high tensile strength steel, which is capable of lightening the car body while maintaining its strength, is rapidly expanding.

In the hot rolling of high tensile strength steel in the hot strip rolling process, deteriorations in dimensional accuracy and increases in rolling trouble become problematic. High tensile strength steel is added with a variety of alloy elements, and therefore, the rolling load becomes higher. The deformation of rolls of a rolling mill thus becomes larger than those in the rolling of mild steel, and it becomes difficult to maintain finished dimensions, particularly sheet profile of high accuracy. Furthermore, high rolling loads are prone to cause problems such as sheet walking at the steel sheet tail end part and larger flatness deficiency. These result in rolling trouble defined as folded tail edge rolling.

To maintain high productivity and low production cost in the hot rolling process even when the production ratio of high tensile strength steel is high, mixed rolling technology, which can assess crown controllability and control the crown online with high accuracy, is necessary to roll mild steel and high tensile strength steel in the same rolling schedule. The basis of this is an online model capable of predicting rolling characteristics of high tensile strength steel, particularly the sheet profile.[1)]

2. Conventional Sheet Profile Prediction Technology

The rolling load of high tensile strength steel is high, sometimes reaching as high as twice that of mild steel. The effect of such a high rolling load deteriorates the sheet profile prediction accuracy, wherein roll deformation sought with calculation is also used. When the sheet profile prediction deteriorates, a flatness prediction accuracy calculated by a sheet profile prediction model deteriorates greatly and flatness deficiency takes place. When flatness deficiency occurs, the sheet becomes wavy in rolling, and normal rolling becomes difficult. In particular, if the buckle at the center is excessive, the sheet may tear in the center and problems such as restricting rolling speed and/or troubles in rolling are caused. Furthermore, the demand for appropriate flatness is strong as defective flatness causes larger uneven temperature distribution in cooling after finish rolling.

Furthermore, in the rolling of high tensile strength steel where

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the rolling load is high, an asymmetric state of rolling takes place in the widthwise direction and tends to grow larger in rolling. Where asymmetry of this kind exists, the asymmetric rolling speed distribution of the rolled material in the widthwise direction is developed, and due to the asymmetric rolling speed distribution, an angular velocity is added to the rolled material; the rolled material walks sideward, and its direction of rolling deviates from the normal direction of rolling. When the rolled material walks sideward during rolling, the edge may collide with the side guide and cause it to buckle, resulting in the problems of a rolling folded edge and damage on rolling rolls thereby.

As mentioned above, when inappropriate flatness and/or sheet walking take place, problems such as the following can be caused: deterioration in productivity and an increase in the production cost due to restrictions imposed on the rolling speed, an increase in operation shut downs due to increased problems, and a deterioration in quality due to roll marks being printed on rolled materials and an uneven temperature distribution being developed during cooling.

To prevent this, rolling mill conditions are established by preparing and rolling high tensile strength steel materials termed "lead materials" to gradually increase the rolling load level. By changing the rolling mill set up with the operators' skill on a step by step basis by observing flatness and sheet walking, however, in the mixed rolling of mild steel and high tensile strength steel, since materials having different rolling loads have to be rolled alternately, employment of such a countermeasure is impossible.

To solve the abovementioned problem, a model capable of predicting sheet profile with high accuracy, even for high tensile strength steel, is required. Also this model must be applicable to online control use. The function of the online profile prediction model is shown in **Fig. 1**.[2] The online sheet profile prediction model is directly used for improving the calculation accuracy for sheet profile and flatness controls, and it also effectuates the sheet walk control by providing a highly accurate influence coefficient that denotes the relationship between the amount of leveling required for sheet walk control and the amount of sheet walking.

Conventionally, a matrix model has been used for the sheet profile prediction calculation.[3, 4] The matrix model is a method of predicting sheet profile with high accuracy by linking rolling mill roll deformation and rolling load and by iterative calculation.

As **Fig. 2** shows, the subjects of the calculations, such as rolled material and rolling rolls, are divided into segments in the widthwise direction and the rolling load and the deformation within a segment are treated as constants. Work roll flattening, roll center axis deflection, and so on are sought for by calculation, considering the displacement conformity condition with respect to back-up-rolls. As shown in **Fig. 3**, distributions of tension are sought for through the change in sheet profile. This method is called a tension-feed-back calculation and requires convergent calculation in a general solution method.

As a precise calculation method for tension-feed-back effect, Formula (1) has been proposed wherein the front and back tension distributions are calculated from the entry and the exit side sheet thickness distributions, respectively, taking the sheet thickness distribution at the neutral point as the base.[5]

$$\sigma_{Ti} = \frac{E \cdot \sum_j \eta_j \cdot \Delta\varepsilon_{Hj} \cdot h_j \cdot \Delta x_j}{\sum_k h_k \cdot \Delta x_k} - E \cdot \eta_i \cdot \Delta\varepsilon_{Hi} + \sigma_T \qquad (1)$$

Where: i, j, and k denote the divided segments
σ_{Ti} : Front or back tension
E : Young's Modulus
η_i : Shape transformation coefficient [6]
$\Delta\varepsilon_{Hi}$: Deviation in the divided segment i from the center segment, of sheet thickness strain at entry or exit side vs base sheet thickness at the neutral point
h_i : Sheet thickness at entry or exit
Δx_i : Width of ith divided segment
σ_T : Average of σ_{Ti}

It is considered that, even if a model as robust as the one mentioned above is used, sheet profile prediction accuracy deteriorates

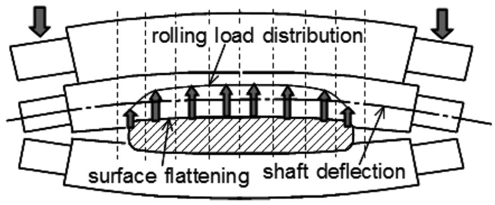

Fig. 2 Calculation of roll deformation

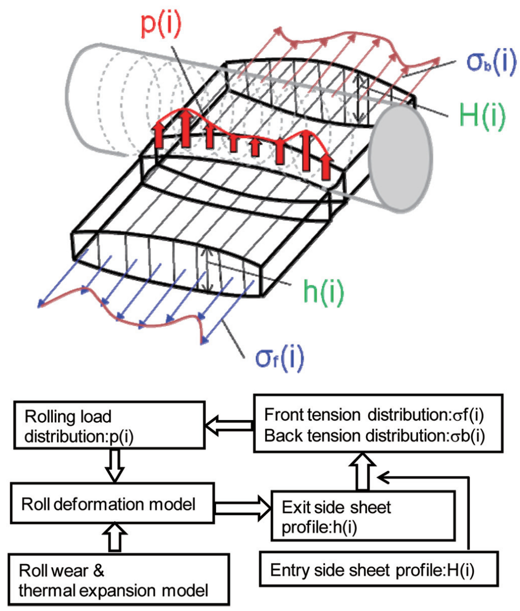

Fig. 3 Flow of tension feed back calculation

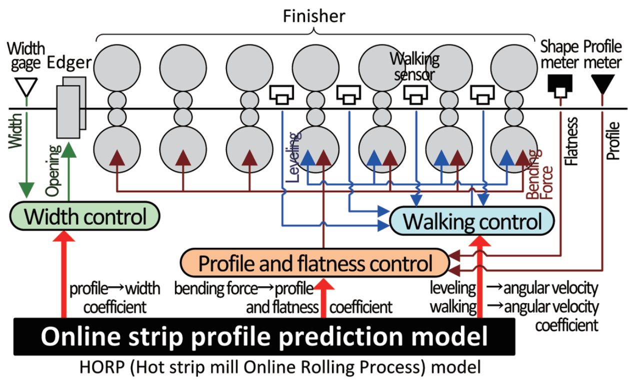

Fig. 1 Functions of online profile prediction model

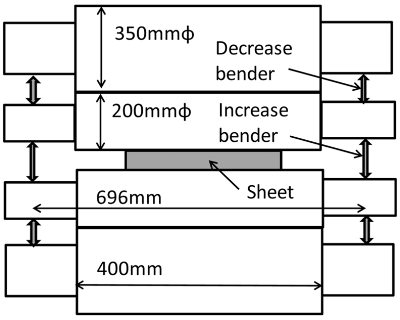

Fig. 4 Model mill

Table 1 Experiment conditions

	Case 1	Case 2	Case 3
Material	Low carbon steel		
Thickness / mm	3		
Sheet crown / μm	0		
Width /mm	250		
Reduction / %	30		
WR diameter / mm	200	100	200
Temperature / ˚C	900	900	700
WR speed / mpm	60		
Rolling load / ton	72	50	119

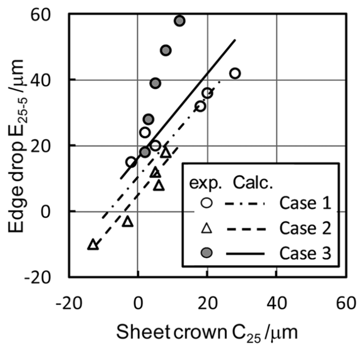

Fig. 5 Accuracy of edge drop with conventional model

in the rolling under a high rolling load and/or in the rolling of a thin sheet due to poor accuracy in rolling load distribution prediction in the edge region of a sheet.[7)]

Hot rolling tests were conducted using a model mill (shown in **Fig. 4**) based on the conditions shown in **Table 1**. The relationships between the sheet crown at the position 25 mm from the edge of a sheet after rolling, C_{25}, and the edge drop between the points at 25 and 5 mm from the sheet edge, $E_{25\text{-}5}$, were studied, the result of which is shown in **Fig. 5**. In the rolling of ordinary steel at 900°C, the relationship between the sheet crown and the edge drop can be predicted with high accuracy even if the conventional model is used. However, it is shown that an increase in edge drop cannot be predicted sufficiently in the rolling at 700°C under high rolling load becoming 1.5 times higher.

Furthermore, it is known from **Fig. 6** that, even in the case of rolling with a relatively larger sheet crown, the edge drop is underestimated by the conventional model. FEM-calculated values in the figure have been obtained by using the CORMILL System.[8)] The results of the calculation with FEM show good agreement with the measured values. However, when the result of rolling load distribution calculated with the conventional matrix method is compared with the calculation result with FEM, it is clear from **Fig. 7** that the difference in sheet profile prediction is caused by the difference in rolling load at the width edge.

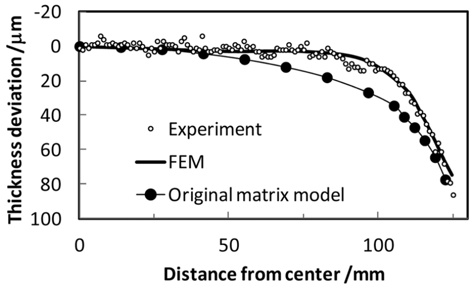

Fig. 6 Difference of sheet profile between conventional model and FEM

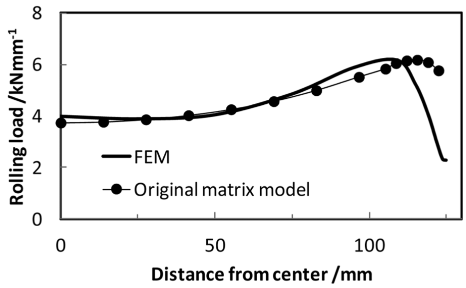

Fig. 7 Difference of rolling force deviation between conventional model and FEM

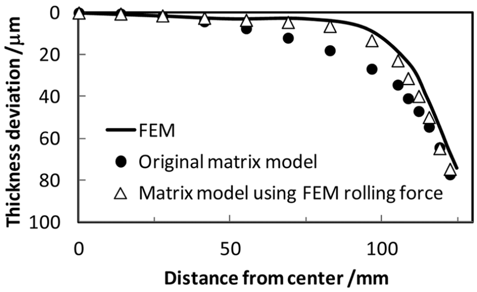

Fig. 8 Effect of rolling force deviation to profile prediction model's accuracy

In **Fig. 8**, the result of the sheet profile calculation is shown, wherein the result of the calculation of rolling load distribution obtained by FEM is fed to the conventional matrix method. Since the sheet profile is calculated to be in good agreement, it is shown that improvement in the calculation method of rolling load distribution in the width edge region will suffice.

3. Improved Technology

3.1 Enhancing the accuracy of the sheet profile prediction model

In order to study the cause of the difference in rolling load distribution as shown in Fig. 7, FEM analysis was conducted assuming that the rolling roll is a rigid body. Analysis conditions are shown in **Table 2**. Assuming that the entry steel sheet profile is rectangular, the analysis was conducted for the case in which the work roll crown is convex, flat, and concaved. The distribution of the rolling

Table 2 Analysis conditions

Mill dimensions	
Work roll diameter	200 mm
Barrel length	400 mm
Rolling conditions	
Entry thickness	3.0 mm
Exit thickness	2.1 mm
Width	250 mm
Entry strip profile	Rectangle
Work roll crown /dia.	50, 0, −50 μm
Flow stress	100 MPa
Friction coefficient	0.35

load and the tension distribution are shown in **Figs. 9** and **10**, respectively.

In the rolling with flat rigid rolls, the rolling load is uniform towards the neighborhood of the width edge. However, at the width edge, the rolling load drops to about half of its value at the center of the width. The same phenomenon is also observed in the maximum rolling load distribution in the widthwise direction in the case of rolling a plasticine material having a rectangular entry profile with flat metallic rolling rolls.[9] Thus, under the condition where the rolling roll is almost a rigid body, roll flattening and deflection are very small, and the material is uniformly deformed in both the center and the width edge sections. In addition, strain in the widthwise direction at the edge section scarcely exists. From the plastic flow condition of Levy-Mises shown in Equation (2), $d\varepsilon_W$ is almost zero at the width edge, and as σ_W is zero based on the boundary condition, the hydrostatic pressure σ_m also becomes almost zero.

$$\frac{d\varepsilon_l}{\sigma_l - \sigma_m} = \frac{d\varepsilon_h}{\sigma_h - \sigma_m} = \frac{d\varepsilon_w}{\sigma_w - \sigma_m} = d\lambda \qquad (2)$$

Where ε : Plastic strain
σ_m : Hydrostatic pressure

Suffixes of l, h and w denote longitudinal direction of rolling, sheet thicknesswise direction, and sheet widthwise direction, respectively.

At the width edge, as constraint in the widthwise direction is low, the lateral spread strain is easily developed primarily, However, under the rolling condition with rigid flat rolling rolls, the strain in the widthwise direction can hardly be developed, and stress in the sheet thicknesswise direction and in the rolling direction, which constrain lateral spread, is produced. In Equation (2), as $d\varepsilon_w$ is nearly zero regardless of the position in the widthwise direction, the stress in the widthwise direction σ_w becomes almost equal to the static hydraulic pressure stress σ_m, and the distribution of σ_w in the widthwise direction becomes almost equal to the distribution of σ_m in the widthwise direction. Likewise, as $d\varepsilon_l$ and $d\varepsilon_h$ are uniform in the widthwise direction and do not change, $\sigma_l - \sigma_m$ and $\sigma_h - \sigma_m$ do not change, and the changing of the stress in the widthwise direction depends solely on the changing of the static hydro pressure component. This means that compressive stress in the sheet thicknesswise direction and in the widthwise direction become lower as the hydrostatic pressure component becomes lower, while tensile stress in the longitudinal direction increases.

When the crown of the work roll (WR) is changed, the result of the calculation shows that the rolling load distribution and the tension distribution change in accordance with the change of the sheet

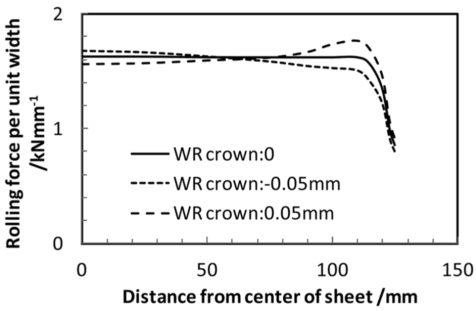

Fig. 9 Calculated distributions of rolling force

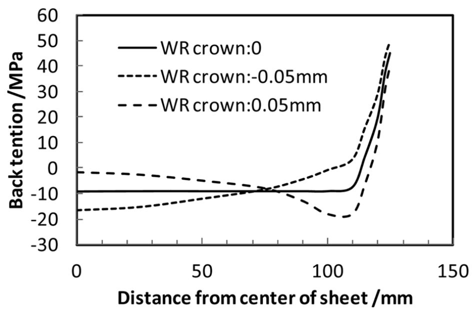

Fig. 10 Calculated distributions of back tension

profile, or, more specifically, the change of percentage sheet crown in the widthwise direction with respect to the rolling load and the tension distribution in the case of the WR crown being zero (which is taken as standard).

In the conventional matrix model, the calculation method works with the assumption that tension acts and the rolling load decreases in accordance with the sheet strain distribution in the widthwise direction, when it takes place. Therefore, rolling load distribution is not developed in the calculation of a case in which the sheet thickness strain distribution in the widthwise direction is zero, like in the case of the WR crown being zero, and elastic roll deformation is not taken into account.

Therefore, when the change in percentage sheet crown is zero, the rolling load distribution is similar to that observed when the change in the WR crown is zero, as shown in Fig.9, and, when a strain distribution in the thicknesswise direction arises, strain distribution in lengthwise direction is induced. A new calculation method has been found by incorporating the method of calculating the tension-feed-back effect of the front and back tensions and the rolling load changes in accordance with the lengthwise strain distribution (**Fig. 11**).

In the new calculation method, as shown in Figs.10 and 11, there is a standard distribution wherein the front and back tension increases at the edge portion when there is no sheet thickness strain distribution in the widthwise direction, to which tension distribution of tension-feed-back effect is to be added. The specific calculation method for tension distribution σ_{tTi} is shown below.

$$\sigma_{tTi} = \sigma_{Ti} + \sigma_{T0i} \qquad (3)$$

Where σ_{Ti} : Tension distribution based on the tension-feed-back effect obtained by formula (1)
σ_{T0i} : Front and back tensions when the sheet strain in the widthwise direction is zero.

σ_{T0i} is obtained by the following formulae, where decreasing rolling load distribution is approximately expressed by a quadratic

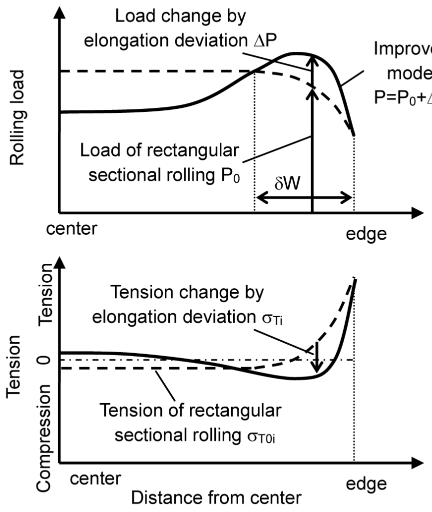

Fig. 11 New rolling load and tension distribution prediction model

function with respect to the widthwise direction, and also relies on the assumption that the front and back tensions are equal.

$$\sigma_{T0i} = \left(1 - \frac{3W}{3W - \delta W} \cdot f(x)\right) p_m \quad (4)$$

$$f(x) = \begin{cases} 1 & : x \le 0.5W - \delta W \\ 1 - \dfrac{1}{2}\left(\dfrac{x - (0.5W - \delta W)}{\delta W}\right)^2 & : 0.5W - \delta W \le x \end{cases} \quad (5)$$

$$p_m = (1 - \delta W/3W)\, p_c \quad (6)$$

Where W : Width of sheet
x : Position in the widthwise direction, 0 in the center of the width, and $W/2$ at the extreme width edge
P_c : Average rolling pressure in the center of the width obtained by dividing the rolling load per unit width with the projected length of arc of contact
δW : Region of decreasing rolling load at the width edge.

In the above tension calculation model, the rolling load distribution is not obtained unless the shape change coefficient η in Formula (1) and the region of decreasing rolling load at the width edge, δW, in the Formulas from (4) to (6), are provided.

η is a parameter that correlates the change of thickness strain deviation with the tension at the entry and exit of the roll bite. As found from the result of the tension distribution calculation shown in Fig. 10, and its influence in the range of δW from the edge is considered to be declining, η is assumed to have the distribution as expressed in Formula (7), which declines at the width edge region. This behavior of declining is expressed by a quadratic function which becomes zero at the extreme edge, as proposed by Takahashi. et al.[10)]

$$\eta(x) = \begin{cases} \eta_c & : x \le 0.5W - \delta W \\ \eta_c \left\{1 - \dfrac{1}{2}\left(\dfrac{x - (0.5W - \delta W)}{\delta W}\right)^2\right\} & : 0.5W - \delta W \le x \end{cases} \quad (7)$$

Where W : Width of sheet
x : Position in the widthwise direction, 0 in the center of the width and $W/2$ at the extreme width edge

η_c is the value of shape transformation coefficient in the center region, determined experimentally.

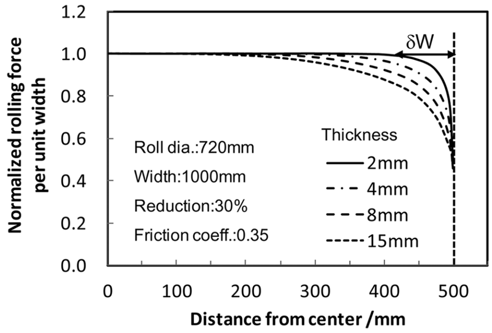

Fig. 12 Influence of thickness to δW

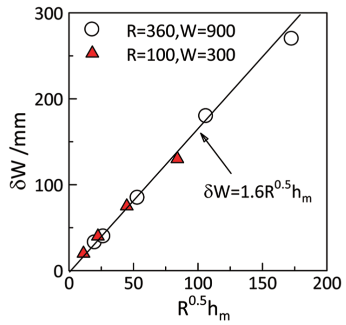

Fig. 13 Influence of thickness and roll radius to δW

The characteristics of δW were studied with three-dimensional FEM analysis. The FEM analysis was conducted under the condition of rectangular-sectioned material at the entry side and a flat rigid roll in order not to cause sheet thickness deviation under the conditions simulating the laboratory and the actual rolling mills. The coefficient of friction between the rolled material and the work roll was assumed to be 0.35 for the purposes of the calculation. From the calculation results shown in **Figs. 12** and **13**, the length of δW at the width edge, wherein the rolling load declines, has been formulated as Formula (8) depending on the average sheet thickness and the roll radius, R.

$$\delta W = 1.6 R^{0.5} h_m \quad (8)$$

where the average sheet thickness h_m is the value defined by the following equation using entry sheet thickness H_c and exit sheet thickness h_c.

$$h_m = (H_c + 2h_c)/3 \quad (9)$$

3.2 Application of the matrix model to online usage

In the online calculation, application of the matrix model, a general method of solution, was difficult because of its inability due to time constraints to repeat the calculation to achieve the desired level of accuracy. Conversely, however, a calculation method like Equation (10) which does not require repetition of the calculation has been developed. This is an approximation by a linear expression using partial differential coefficients of rolling load distribution in the widthwise direction and entry and exit sheet thickness distribution.[10, 11)] Using this method, calculation in the matrix model in a short time is possible, and its use for online calculations is also possible. Even if the new tension distribution calculation method explained in the foregoing section is introduced, the matrix model can be used without an increase in computational load.

$$p_i - p_c = \frac{\partial p}{\partial h}\left(h_i - h_c\right) + \frac{\partial p}{\partial H}\left(H_i - H_c\right) + \frac{\partial p}{\partial \sigma_f}\left(\sigma_{fi} - \sigma_{fc}\right) + \frac{\partial p}{\partial \sigma_b}\left(\sigma_{bi} - \sigma_{bc}\right) \tag{10}$$

Where p : Rolling load per unit width
h : Exit thickness
H : Entry thickness
σ_f : Front tension stress
σ_b : Back tension stress
i : ith divided segment

Suffix c denotes a value at the sheet width center. Partial differential coefficients of rolling load vs sheet thickness and tension can be easily derived by using, for example, the rolling load calculation formula of SIMS corrected for tension.

The effect of improvement in the sheet profile and crown prediction accuracy by using the matrix model with the improved rolling load distribution calculation method as mentioned above has been confirmed with actual data. **Figure 14** shows the improved prediction accuracy of a sheet profile, including edge drop, for a thin high tensile strength steel sheet rolled in the hot strip mill of the Kashima Works of Nippon Steel & Sumitomo Metal Corporation.

The result of the improvement in sheet crown prediction accuracy confirmed in the mill is shown in **Fig. 15**. The effect of the improvement in prediction accuracy in thin products is remarkable, in particular where the rolling load tends to become high. When the edge drop prediction accuracy is evaluated, it is also found that the effect in the improvement is larger as the sheet thickness becomes smaller (**Fig. 16**). By building the highly accurate online sheet profile prediction model developed with the improvements mentioned above into the HORP (Hot strip mill Online Rolling Process) model that had been developed as a finishing mill set up model,[12] it has become possible for the HORP model to be used for setting a calculation for roll to aimed finished sheet profile without deteriorating the shape during finishing mill rolling, even in the alternate rolling of high tensile strength and mild steel where there is a large difference in the rolling load.

Furthermore, the model also plays an important role in sheet-walking control[13] which uses interstand walking sensors. As a walking rolled material is translated with an angular velocity, the amount of walking at a walking sensor (amount measured) does not agree with the amount of walking at the downstream rolling mill stand position (amount to be controlled). For the compensation, the amount of walking at the rolling mill stand position is predicted according to the amount of walking measured based on a state equation model, and the optimum amount of leveling operation is rendered. In order for the method to function effectively, the influence coefficient $K_{\eta S}$ of the leveling amount over the angular velocity distribution coefficient (value of angular velocity divided by travelling velocity of a rolled material) and the influence coefficient $K_{\eta y}$ of the amount of sheet walk at the rolling mill stand over the angular velocity distribution coefficient need to be predicted with high accuracy.

The angular velocity of a rolled material on the entry side of a rolling mill stand, when sheet walking becomes problematic, corresponds to the entry side rolling speed distribution at the time of the tail end being released from the previous rolling mill stand. Rolling speed distribution on the exit side of the subject rolling mill stand does not exist when the rolled material is still in the state of tandem rolling. Therefore, the entry side rolling speed distribution corresponds to the change in the ratio between the entry and exit thicknesses. Accordingly, when the sheet profile prediction accuracy is improved, the accuracy of $K_{\eta S}$ and $K_{\eta y}$, the influence coefficients related to angular velocity in sheet walking, are improved. The improvement in the accuracy of the influence coefficient in sheet-

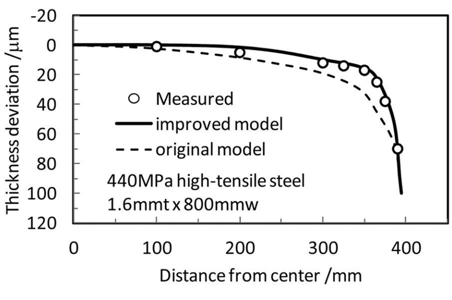

Fig. 14 Improvement of strip profile prediction accuracy

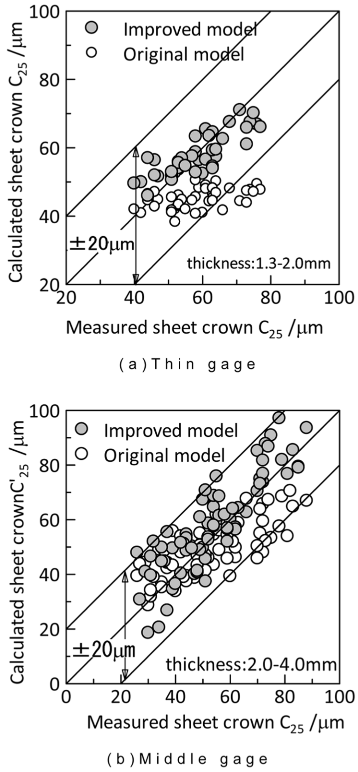

Fig. 15 Improvement of strip crown prediction accuracy

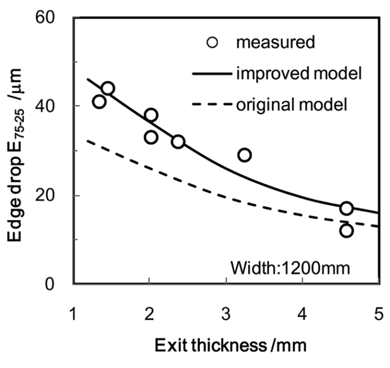

Fig. 16 Improvement of edge drop prediction accuracy

walking control is linked to the improvement in the control accuracy of sheet-walking control via improvement in setting accuracy of control gain.

As, with the improved HORP model, the sheet profile prediction accuracy for high rolling load material, like high tensile strength steel, has been improved to the same level with the sheet profile prediction accuracy for low rolling load material like mild steel, sheet-walking control of high tensile strength steel has also become practically applicable. Furthermore, in the case of high tensile strength steel, not only the rolling load, but also the rolling conditions such as sheet width, resistance to deformation and rolling speed vary greatly as compared with the conditions of rolling mild steel. By using the HORP model designed for asymmetrical rolling, high-accuracy sheet-walking control can be realized based on online calculation conducted for varying rolling conditions of each rolling material.

Figure 17 shows the results of the comparison of $K_{\eta S}$, $K_{\eta y}$ and the proportional control gain in leveling operation derived from $K_{\eta S}$ with respect to high tensile strength steel and mild steel sheets of thickness of 1.5–1.7 mm. Though width is influential in both steels, it is found that both $K_{\eta S}$ and the control gain of high tensile strength steel are smaller than those of mild steel. As this shows, such influential factors in sheet-walking control as sheet width, material, rolling speed, and so on are input to the HORP model and used for the control and, based on the result of the calculation, real time control parameters like control gain are automatically set, and therefore highly responsive sheet-walking control becomes possible.

3.3 Sheet crown controllability meeting mixed scheduled rolling

In case high tensile strength steel having high rolling load is rolled under the rolling mill setting for mild steel, the finished sheet crown becomes larger as roll deflection and flattening deformation become larger and the sheet thickness accuracy deteriorates. In order to carry out mixed scheduled rolling where high tensile strength and mild steels are rolled alternately with the same rolls, thus reducing finished sheet crown, finish mill controllability of sheet crown is needed. Shown is an example of the calculation of sheet crown controllability required for the finishing mill to execute mixed scheduled rolling with respect to the rolling production condition of different steels conducted under the conditions shown in **Tables 3** and **4**.[14)]

The result of the calculation with respect to the allowable sheet crown range at each stand is shown in **Fig. 18**. In this calculation, the following two ranges were calculated; the required sheet crown range necessary for rolling a sheet with an aimed finished crown of within 30 μm under the condition that allowable steepness at the exit of each mill stand is to be within ±2%, and the range of sheet crown attainable from a rough bar with crown of 200 μm. The overlapping range is taken as the allowable sheet crown range. **Fig. 19** shows the work roll crown of the quadratic curve required for each rolling mill stand calculated with the abovementioned matrix model based on a sheet crown pass chosen in the allowable sheet crown range and rolling load condition. As can be deduced from the figure, for the schedule-free rolling of high tensile strength and mild steels, power-

Table 3 Mill dimensions

Work roll diameter	740 mm
Back up roll diameter	1 540 mm
Barrel length	1 780 mm
Span of loading points	2 820 mm

Table 4 Analysis conditions

Material		Mild steel (C = 0.05 mass%)	High tensile strength steel (HT590 MPa)
Width /mm		950	1 200
Exit thickness / mm	R	36	29
	F1	23.15	16.21
	F2	15.48	10.51
	F3	10.9	7.45
	F4	7.69	5.27
	F5	5.98	4.08
	F6	4.62	3.26
	F7	3.86	2.83

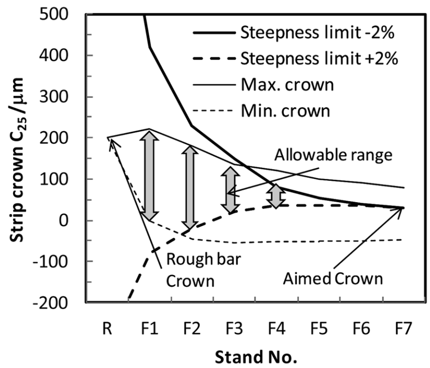

Fig. 18 Allowable range of strip crown (HT590 MPa)

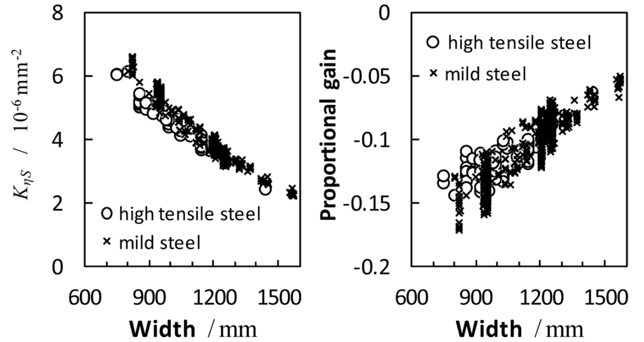

Fig. 17 Influence coefficient and control gain calculated by online HORP model

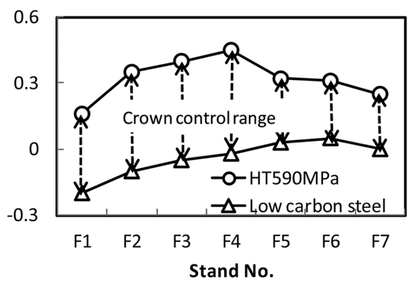

Fig. 19 Required capacity of crown control

ful sheet crown controllability is required in the upstream stands of the finishing mill where the amount of rolling load change is large.

Furthermore, the crown path is set taking into account the sheet crown and shape on the exit side of the finishing mill, the inter-stand sheet shape, and so on. However, in the mixed scheduled rolling of mild and high tensile strength steels, the sheet crown controllability tends to become insufficient and loosening of constraining conditions is needed. In order to obtain the optimum crown path without loosening the constraining conditions more than necessary, the crown path is determined by formulating it as a quadratic programming problem.[1)]

4. Result of Application to Actual Rolling Mill

Figure 20 shows an example of mixed scheduled rolling of high tensile strength and mild steels. From the graph at the top, it is known that steels of different widths and sheet thicknesses are mixed and that rolling conditions vary greatly in each rolling. In the graph in the middle, the state of crown control at the F3 rolling mill stand, where the rolling load difference between high tensile strength and mild steels is large, is shown in the form of an equivalent quadratic work roll crown. It is known that crown control is being conducted in the same crown control range as that shown in Fig. 19. The bottom graph shows the deviation of the actual values from the aimed values of C_{25}, the finishing mill exit sheet crown at the position 25 mm from the sheet edge. It is known that the crown size is controlled to the accuracy of approximately ±20 μm. This accuracy is equivalent to the accuracy of mild steel[10)] when it is rolled by itself.

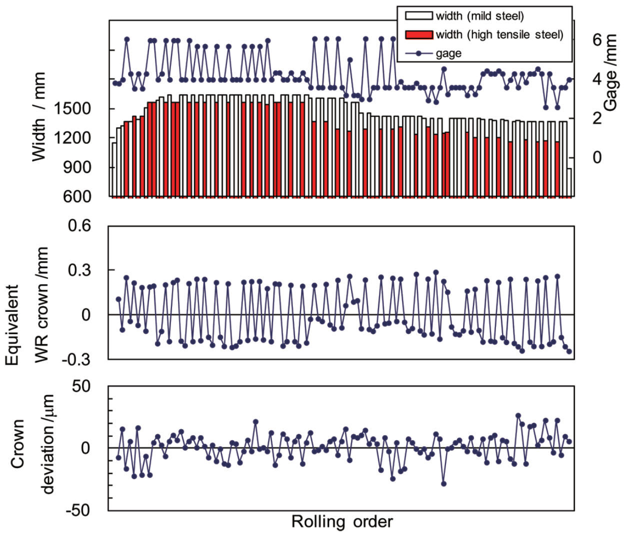

Fig. 20 Example of mixed scheduled rolling of high tensile strength and mild steel

5. Conclusion

Subject to hot finishing rolling, a model capable of predicting with high accuracy the sheet profile of high tensile strength steel that yields high rolling load has been developed and applied to online control. By using the model, crown controllability required for mixed rolling where high tensile strength steel which yields high rolling load and mild steel with low rolling load are rolled with the same work rolls was studied, and it was clarified that large crown controllability is required in the upstream stands of the finishing mill where change in the rolling load is large.

By utilizing such technology and knowledge, mixed rolling of high tensile strength and mild steels has been accomplished. In the mixed rolling, it has been possible to realize sheet crown control of accuracy equivalent to that of solely rolled mild steel. Furthermore, the deterioration in productivity due to defective flatness and the like have not occurred. The highly accurate sheet profile prediction model is also utilized in sheet-walking control which employs walking sensors installed interstand, and high productivity rolling has been accomplished by eliminating rolling troubles due to sheet-walking. These technologies are contributing to the increased automation of hot finish rolling mill by, for example, lowering the frequency of operators' manual intervention.

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