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Crown Control of Hot-Rolled Stainless Steel Coils

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Crown Control of Hot-Rolled Stainless Steel Coils*


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1 Introduction

Factors that determine the dimensional accuracy of hot-rolled coils are the thickness, width, and crown (indicating a center height of strip as shown in Fig. 1) of the strip. With respect to thickness and width control, AGC (automatic gauge control) and AWC (automatic width control) have been introduced in many hot strip mills. In recent years, the adoption of hydraulic AGC and hydraulic AWC with better response characteristics has been actively carried out.[1]

To reduce strip crown, such means as differential rolling with a single roll drive[2] and high-power work-roll benders[3] have been used. At Kawasaki Steel, rolling with trapezoid-camber work rolls[4] has been adopted to meet users' requirements for smaller strip crowns. However, completely satisfactory results have not been obtained with any of these methods, and it has been impossible to meet requirements especially with square cross section strips (called "dead flat") such as in stainless steel strips.

In recent years, crown specifications have become increasingly strict and, in response, steel companies have carried out or planned the introduction of crown control mills. Kawasaki Steel has positively adopted crown control mills since early on. In June 1983, the company installed a Kawasaki Steel work roll shifting mill (K-WRS mill), which is a 4-high mill, in the finisher of the Chiba Works No. 1 hot strip mill.[5] In September 1983, an HC mill (high crown control mill),[6] which is a 6-high mill, was installed in the finisher of the Mizushima Works hot strip mill. Furthermore, a crown control mill combining a K-WRS mill and high-power work-roll bender will be installed in the finisher of the Chiba Works No. 2 hot strip mill in the spring of 1986. When this revamping is completed, all three Kawasaki Steel hot strip finishing mills will be crown control mills.

This report describes the crown control methods for

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the K-WRS mill and HC mill and the results of rolling of stainless steel strips on these mills.

2 Crown of Hot-Rolled Steel Strips

When reduction is applied to material, the rolling reaction force from the material causes roll bending, and flattening of the roll surface. Especially in materials with higher deformation resistance than mild steels, such as stainless steel strip, the force of this reaction on the rolls is great, and deflection and flattening are accordingly great. Furthermore, wear and thermal expansion of rolls occurs in the course of rolling. Roll wear increases in near proportion to the mathematical product of rolling load and total coil length rolled by the same roll. Thermal expansion of rolls occurs due to heat input to the roll caused by the contact, friction, and radiation between the material being rolled and the roll. Since, in the roll axial direction, there is a difference in the amount of thermal expansion between the barrel center pósition, where heat is mainly received, and the roll ends, where receive no heat, expansion is great at the axial center of the roll and small at the roll ends. This distribution of thermal expansion is called thermal crown.

As is apparent from the foregoing, the crown of hot-rolled steel strips is governed by the four factors: deflection, flattening, wear, and thermal expansion (thermal crown).

3 Conventional Crown Control

The conventional crown control consists mainly of relieving the deflection of the work roll due to the reaction force from the strip. For this purpose, methods adopted include one in which the pressure of a bender is used to broaden the two ends of the work roll and another in which the initial curve of the work roll is made convex in order to relieve the contact pressure at roll ends. The latter method is also effective in directly reducing the crown by utilizing the geometrical shape of the roll.

Although the bulging at the center of strip crown can be reduced by these methods, they have virtually no effect in reducing the partial loss of thickness near the strip edges, called edge drop, shown in **Fig. 1**.

To eliminate the drawbacks of the conventional methods, Kawasaki Steel, earlier than any other steel companies,[4] developed the trapezoid-camber rolling method. **Figure 2** shows schematically a comparison between trapezoid-camber rolling and conventional rolling. In the trapezoid-camber rolling method, the roll gap at strip edges is increased by tapering the work roll barrel edge vicinities. This configuration also substantially reduces contact pressure of the work roll barrel-edge vicinities with the backup roll, and as a result, edge drop

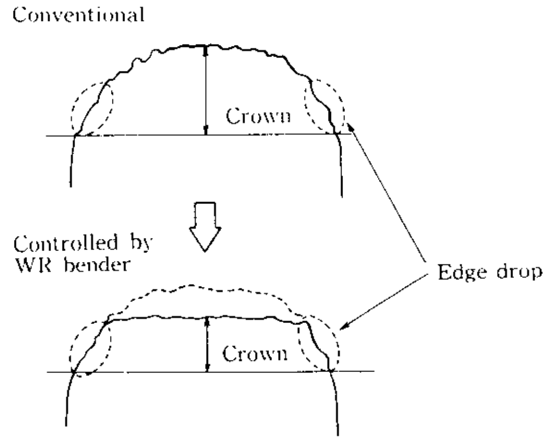


Fig. 1 Effect of WR bender on crown and edge drop of stainless steel strip

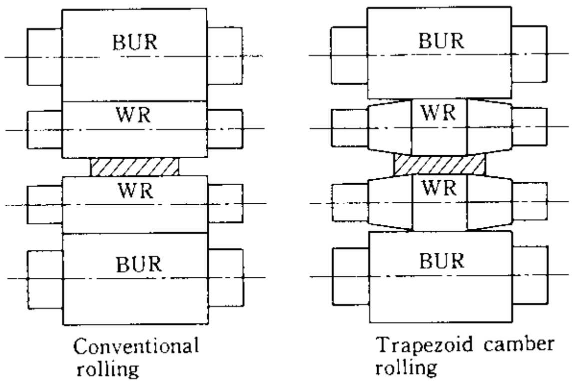


Fig. 2 Schematic diagram of conventional and trapezoid-camber rolling

is improved. However, the fixed shape of the trapezoid-camber roll limits the width of the strip with which the effect of this rolling method can be obtained using the same trapezoid-camber roll, as well as the threadable strip width. This presented difficulties in preparing practical schedules of rolling.

4 Crown Control Mills

The specifications of the K-WRS mill installed in the finisher of the Chiba Works No. 1 hot strip mill and the HC mill installed in the finisher of the Mizushima Works hot strip mill are shown in **Table 1**.

4.1 Crown Control in K-WRS Mill

Methods of using the K-WRS mill are broadly divided into two: Under one method, rolls without taper are cyclically shifted to prevent high spots (abnormal local protuberances in strips formed due to the uneven wear of rolls) rather than to control the strip crown. This method is called the cyclic shifting (CS) method[7,8] and applied to the rolling of low carbon steel for cold rolling.

Table 1 Specifications of K-WRS mill and HC mill

Mill	Item	Specification
Chiba No. 1 hot strip mill (K-WRS)	Roll size	WR : 597~ 700 $\phi \times$ 1 700 L mm BUR: 1 118~1 255 $\phi \times$ 1 372 L mm
	Work roll shift	Stroke: ±275 mm max Force : 100 tf max
	WR bending force	Increase: 53 tf/chock max
Mizushima hot strip mill (HC)	Roll size	WR : 585~ 685 $\phi \times$ 2 380 L mm IMR : 540~ 675 $\phi \times$ 2 345 L mm BUR: 1 190~1 340 $\phi \times$ 2 300 L mm
	Shift stroke	IMR: 0~750 mm WR : ±150 mm
	Work-roll bending force	Increase : 75 tf/chock max Decrease: 75 tf/chock max (only for upper roll)

The other method is the one-side tapered work roll shifting method, which was developed from the trapezoid-camber rolling method and is called the taper-adjusting (TA) method.[8,9] Stainless steel is rolled using the TA method.

In the TA method, to ensure greater crown controllability than with the conventional trapezoid-camber rolling method, each work roll is tapered only on one side, the work rolls are arranged so as to produce central symmetry of the tapers, and the upper and lower work rolls are shiftable axially depending on the strip width. **Figure 3** is a schematic diagram of the TA crown control method. Crown control parameters are the amounts of taper relative to the strip, i.e., E_L (effective length) and E_H (effective height), as shown in **Fig. 4**. In the finisher of Chiba Works No. 1 hot strip mill, the E_L-value can be adjusted over the range of the maximum amount of shift for each roll (275 mm) multiplied by 2. Under the conventional method, the amount of roll taper has been determined on the basis only of the width of the strip that requires special crown control among strips to be rolled in the same rolling campaign. In contrast to this, in the TA method, an appropriate amount of taper can be selected for each width of strips in the same rolling campaign. Under the TA method, therefore, wider ranging strip crown control has become possible, and restrictions on the preparation of rolling schedules have been substantially relaxed.

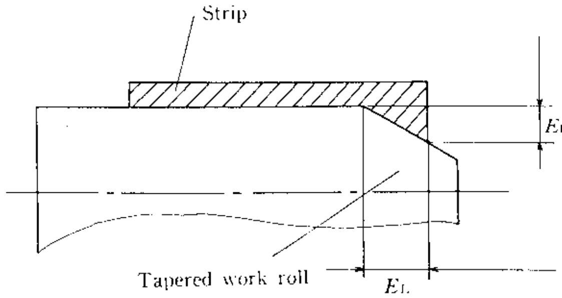


Fig. 4 Definition of E_H and E_L

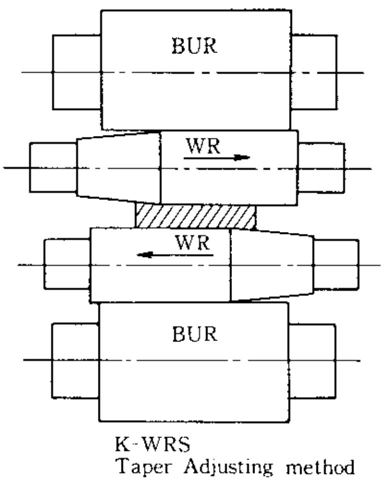
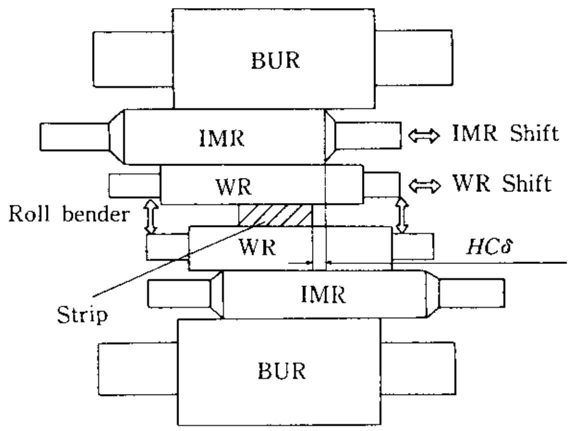


Fig. 3 Schematic diagram of K-WRS mill

4.2 Crown Control in HC Mill[10]

The principle of crown control in a HC mill is shown in **Fig. 5**. The HC mill is provided with intermediate rolls, shiftable in the axial direction, between work rolls and backup rolls. Furthermore, the work rolls also possess shifting mechanisms for use in crown control.

When the intermediate roll is shifted, a noncontact



$$HC\delta = \frac{L - W}{2} \Delta l$$

L: WR barrel length
W: Strip width
Δl: IMR shift

Fig. 5 Schematic diagram of HC mill

area is produced between the work roll barrel edge vicinity and the intermediate roll, reducing the contact pressure of the rolls at the work roll end, and, as a result, decreasing deflection. The amount of deflection of the work roll can be controlled by regulating the amount of shift of the intermediate roll in response to strip width, that is, by changing the distance between the strip edge and the intermediate roll end, or, more precisely, the length of the part of the intermediate roll in contact with the part of the work roll not in contact with the strip (denoted $HC\delta$). The effect of the work-roll bender also increases with increasing amounts of shift of the intermediate roll, i.e., with decreasing $HC\delta$. Therefore, due to the effect of the intermediate roll shift, the HC mill has a greater crown control capability than the conventional 4-high mill. Furthermore, the simultaneous shifting of the work roll permits a wider range of crown control and more freedom in preparing the rolling schedule.

5 Application of Crown Control Mills to Production of Stainless Steel Strips

This section describes results of crown control of stainless steel strips in a K-WRS mill and an HC mill.

5.1 Crown Control of Stainless Steel Strips in K-WRS Mill

The finisher of the Chiba Works No. 1 hot strip mill, where a K-WRS mill is installed, rolls mainly ferritic and martensitic stainless steels.

5.1.1 Effect of change of E_L-value

Figure 6 shows an example of crown change when SUS 430 strips 4.0 mm in thickness and 1 265 mm in width were rolled on the K-WRS mill with varying E_L-values. The crown is evaluated by the strip thickness difference (Cr_{25}), i.e., the difference between the strip thickness at the middle of the strip width and the strip thickness 25 mm from the strip edges.

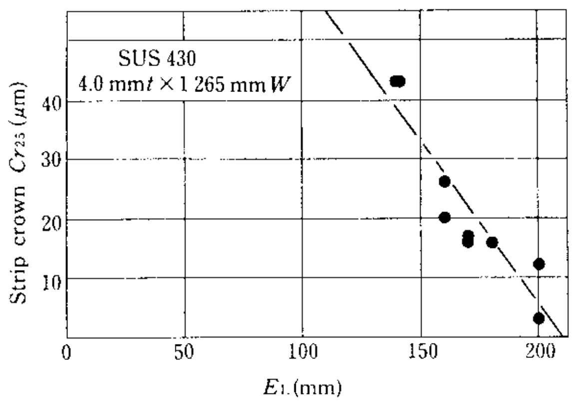


Fig. 6 Effect of E_L changing on strip crown

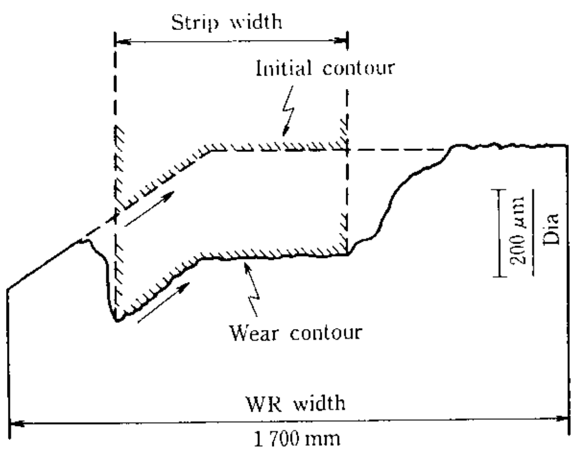
$$Cr_{25} = h_C - \frac{h_{W25} + h_{D25}}{2} \qquad \cdots\cdots\cdots\cdots(1)$$

where

h_C: Strip thickness in the center of strip width
h_{W25}: Strip thickness 25 mm from the work-side strip edge
h_{D25}: Strip thickness 25 mm from the drive-side strip edge

In this case, Cr_{25} can be controlled to about 0 to 40 μm by adjusting the E_L-value with the range 140 mm and 200 mm. To obtain a satisfactory control results with the TA method, it is necessary that the roll wear contour over the course of the rolling campaign is the same as the roll contour initially given. **Figure 7** shows an example of the wear contour of a tapered roll used in the TA method. The taper contour of the worn roll is the same as the contour initially given by roll grinding, and it was also ascertained that the effectiveness of control by E_L adjustment is maintained over the entire course of a rolling campaign.

However, if a larger E_L-value than with the preceding strip is used or a strip wider than the preceding one is rolled when roll wear has proceeded well, large edge drops are formed because the strip is threaded with its edges passing over the box-shaped worn parts of the roll. With the stainless steel SUS 430, which has lower deformation resistance than other stainless steels, it is easy to control crown by adopting large E_L-values. In martensitic stainless steels with high deformation resistance, such as SUS 420J2, large E_L-values may impair thread-



F3 upper WR
Material: high carbon steel
Size: 3.3~3.5 mm$t$ × 668~967 mm$W$
Amount of rolling materials: 602 t

Fig. 7 Typical example of wear contour of tapered work roll after hot rolling

ing, so the usable range of E_L values is limited.

Therefore, the composition of the rolling campaign and the setting of E_L-values should be carried so as to best respond to these points, if the advantages of the TA method are to be fully realized.

5.1.2 Strip crown profile

Variations in the strip crown in a hot rolling campaign are shown in **Fig. 8**. In this campaign, thickness varied between 3 and 4 mm and width between 720 and 1 260 mm. By the conventional methods, good crown control is obtained only with specific sizes even using trapezoid-camber rolls; the average Cr_{25} throughout such a campaign has been about 100 μm. With the TA method, however, it has become possible to control Cr_{25} to 0 to 40 μm throughout a rolling campaign by setting optimum E_L in view of the schedule composition, even if strip width and thickness vary.

Figure 9 shows examples of a typical profile (widthwise thickness distribution composed of the crown, edge drops, high spots, etc.) of SUS430 steel strips rolled by the TA method. As is apparent from this figure, the profiles show an almost square cross section.

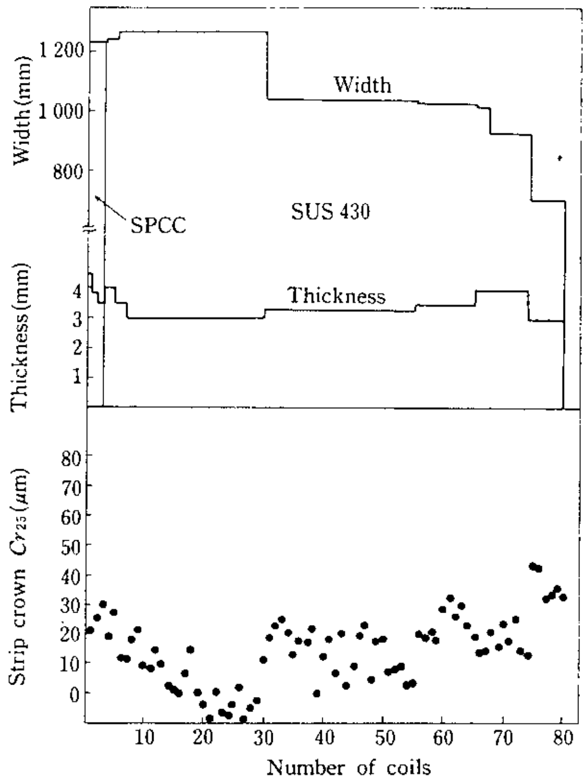


Fig. 8 Change of strip crown in hot rolling campaign by K-WRS mill (SUS 430)

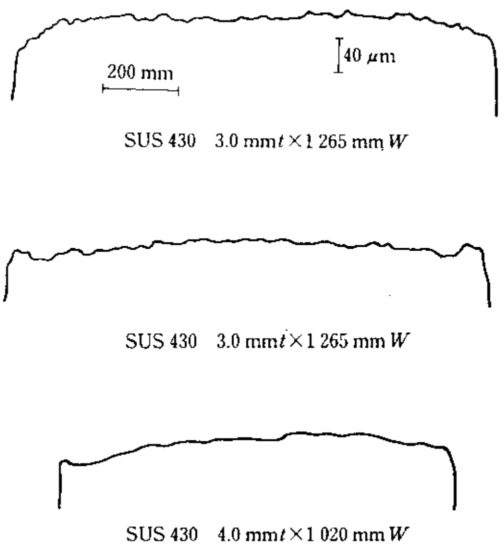


Fig. 9 Typical profiles of SUS 430 steel by K-WRS mill

5.1.3 Results of crown control

Table 2 gives examples of results of crown control of SUS 430, 410 and 420J2 steel strips rolled with the K-WRS mill by the TA method. In the conventional method, Cr_{25} was about 100 μm in the rolling of SUS 430 strips 3.0 to 3.3 mm in thickness and 1 000 to 1 300 mm in width and SUS 410 strips 4.0 to 5.3 mm in

Table 2 Crown control capability in K-WRS mill

Materials	Product size* (mm)	n**	Cr_{25} (μm) (−20 0 20 40 60 80 100 120)
SUS 430	3.3 × 1 000	159	23 (2σ)
SUS 430	3.0 × 1 219	133	4
SUS 410	4.0 ~ 5.3 × 1 000	115	14
SUS 420	5.0 ~ 8.0 × 914 ~ 1 000	73	24
SUS 420 J2	4.0 ~ 5.5 × 914 ~ 1 000	61	48

*Thickness × width
**Number of coils examined
○ Conventional
● K-WRS

thickness and 1 000 mm in width. When the TA method was adopted, Cr_{25} decreased to less than about 40 μm in almost all cases and the average Cr_{25} was 0 to 30 μm, less than 1/3 the values obtained with the conventional methods.

5.2 Crown Control of Stainless Steel Strips in HC Mill

The finisher at the Mizushima Works hot strip mill, where an HC mill is installed, rolls mainly SUS 304 strips which must meet severe thickness tolerances and severe crown requirements. Crown control techniques adopted in this HC mill and results of their application to the rolling of SUS 304 strips are described in the following.

5.2.1 Effect of crown control

Figure 10 shows changes in the strip crown when the amount of shift of intermediate rolls and the work-roll bender force in the F5 to F7 stands were simultaneously changed. Cr_{25} can be controlled to 40 to 50 μm by changing the amount of shift of the intermediate rolls in the range of 0 to 400 mm. It is apparent from the gradients shown in this figure that the effect of intermediate roll shift is a crown change of about 0.1 μm for each 1 mm of shift. Furthermore, it was confirmed that combined application of intermediate-roll shifting and roll benders ensures strip crown controllability of about 70 μm with this product size.

5.2.2 Flatness

The HC mill has a wide crown control capability with SUS 304, in the same way as with mild steels. However, the flatness between stands and on the exit side of the finisher changes with changes in crown ratio (crown/strip thickness) on the exit side of each stand. When using an HC mill to control strip crown, if the crown ratio on the exit side of an upstream stand of the finisher is high, as crown is reduced by adjusting intermediate-roll shift downstream, crown ratio changes greatly. As a result, the flatness between stands and on the exit side of the finisher deteriorates, and positive results may not be obtainable from intermediate-roll shifting. To obtain a profile of square cross section without impairing flatness on the exit side of the finisher, it is necessary to reduce crown in the upstream stands of the finisher. To this end, good results can be obtained from roll shifting without impairing flatness by using convex-curved rolls in the upstream stands of the finisher.

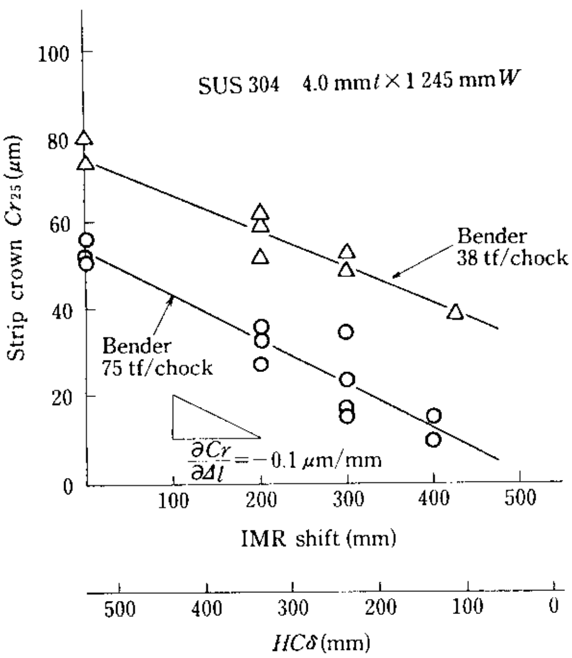


Fig. 10 Effect of IMR shift on strip crown

5.2.3 Edge drop

When rolling is conducted with an HC mill without using trapezoid-camber work rolls, bulging of the strip center crown can be sufficiently controlled. However, it is difficult to prevent the occurrence of edge drops.

In the finisher at the Mizushima Works hot strip mill, edge drops are presently reduced by decreasing rolling loads in the downstream stands of the mill. For this purpose, the following measures are taken:

(1) Raising rolling temperature by increasing the sheet bar thickness and rolling speed
(2) Adoption of a reduction schedule with lighter reductions in downstream stands

Figure 11 shows the relationship between the rolling load in the final stand (F7 stand) and strip crown Cr_{25} when rolling force distribution was changed while maintaining the same rolling conditions otherwise. It was ascertained that reduction of rolling load in the F7 stand results in decreases in strip crown.

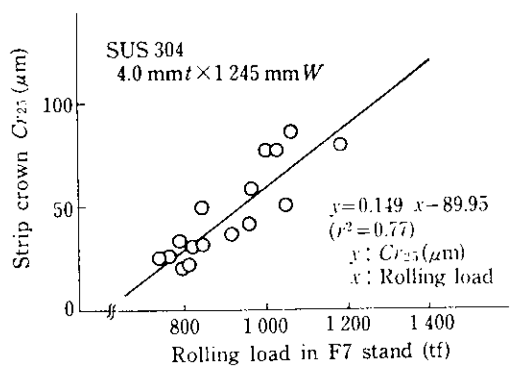


Fig. 11 Relation between rolling load in F7 stand and strip crown

5.2.4 Strip crown and profile

By applying the various techniques mentioned above, it has become possible to achieve target crowns in the rolling of SUS 304 strips. **Figure 12** shows examples of the profile of SUS 304 strips rolled with the HC mill using these techniques. A good profile of almost square cross section was obtained in a 4.0-mm thick strip. In the case of a 2.0-mm strip, however, the profile has somewhat large edge drops due to high rolling loads.

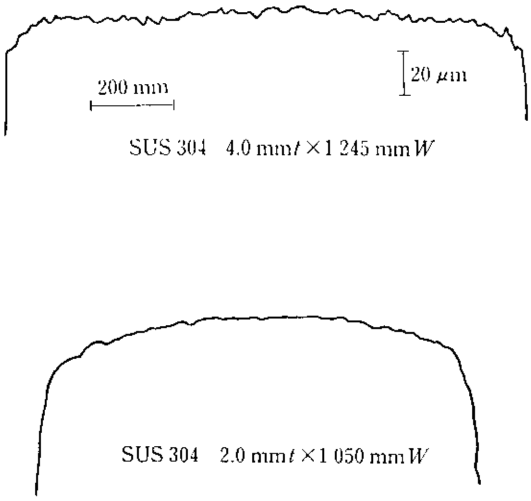


Fig. 12 Typical profiles of SUS 304 steel by HC mill

Figure 13 shows variations in the strip crown in a hot rolling campaign when crown control was conducted with the HC mill. Conventionally, the Cr_{25} of stainless steels in the same rolling campaign is larger than that of mild steels by more than 60 μm. However, if the various above-mentioned control techniques are employed in the HC mill, Cr_{25} can be controlled to the range of 10 to 60 μm, even during a rolling campaign for stainless steels.

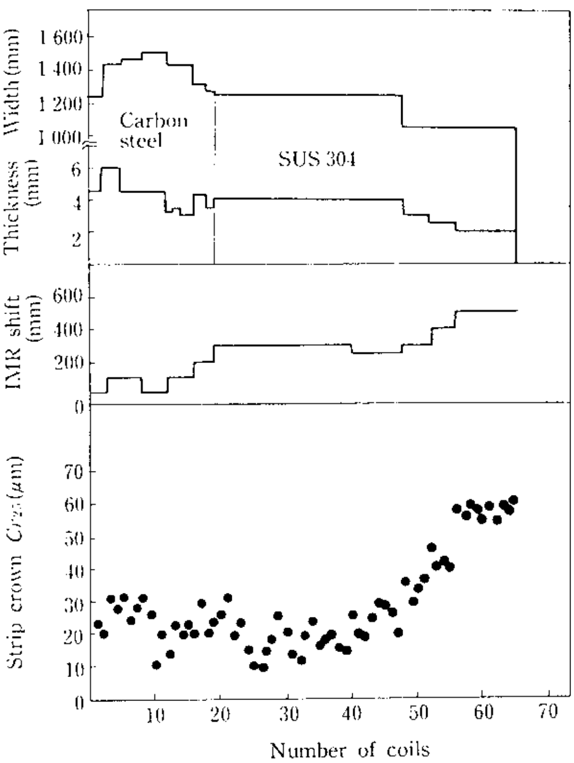


Fig. 13 Change of strip crown in hot rolling campaign by HC mill (SUS 304)

Table 3 Crown control capability-comparison of Cr_{25}-in HC mill

(μm)

Method \ Materials / Size* (mm)		SUS 304	SUS 304
		2.0 × 1 065	4.0 × 1 265
Conventional mill		≤180	≤150
HC mill	①	≤100	≤ 70
	①+②	≤ 70	≤ 50
	①+②+③+④	≤ 60	≤ 40

① IMR shift
② Roll curve changed
③ High temp. rolling at finisher stands
④ Light reduction at the latter stands
* Thickness × width

5.2.5 Results of control

Table 3 gives crown control techniques so far adopted to date, with their respective control limits. By applying the above-mentioned control techniques to the HC mill, it has become possible to reduce the Cr_{25} of SUS304 strips 2.0 mm in thickness and 1 065 mm in width to less than 60 μm from the conventional level of about 180 μm, and that of SUS304 strips 4.0 mm in thickness and 1 265 mm in width to less than 40 μm from the conventional level of about 150 μm, i.e., to less than 1/3 the conventional levels. Furthermore, hydraulic screwdown devices were installed in connection with the adoption of HC mills in F5 to F7 stands. This has made it possible to improve gauge accuracy in the rolling direction. As a result, it has become possible to supply stainless steel strips to meet severe gauge tolerances.

6 Conclusions

Crown control of stainless steel strips is conducted using a K-WRS mill installed in the finisher of the Chiba Works No. 1 hot strip mill and an HC mill at the finisher of the Mizushima Works hot strip mill. As a result, Cr_{25} has been reduced to 23 μm on average in the rolling of SUS 430 strips 3.3 mm in thickness and 1 039 mm in width with the K-WRS mill and to less than 60 μm in the rolling of SUS 304 strips 2.0 mm in thickness and 1 065 mm in width with the HC mill. Thus, both results represent a substantial reduction in strip crown, to less than 1/3 conventional levels. Furthermore, because crown control throughout a rolling campaign has become possible, the range of materials to which crown control is applicable has greatly increased, and much greater freedom has been achieved in rolling schedule preparation (for example, in terms of the rolling order of strips requiring crown control during a rolling campaign).

Kawasaki Steel plans to install a crown control mill combining the K-WRS mill with a high-power work-roll bender at the finisher of the Chiba Works No. 2 hot strip mill in the spring of 1986. With completion of this revamping, all the three hot strip mills owned by the company will have been transformed into crown control mills with the aim of further raising the level of crown control techniques.

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