KAWASAKI STEEL TECHNICAL REPORT
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Tadaaki YANAZAWA** Jun MIYOSHI** Kazuya TSUBOTA**
Takahiro IKEYA** Hiroyuki KIKUGAWA** Kazushi BABA**

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1 Preface

Plates are used for extensive applications such as shipbuilding, general structures, bridges, pressure vessels, etc., and a variety of product dimensions is required. Plate rolling is characterized by the rolling of base steel with relatively fixed thicknesses and widths (hereinafter referred to as slabs) not only in the longitudinal direction but also in the transverse direction in order to get products of diverse dimensions.

When rolling in the longitudinal and transverse directions, nonhomogeneous plastic deformation occurs at both leading and tail ends at each pass. As a result, the top and bottom sections of the rolled plate take an uneven shape. Also, edges from barrel or spool shape and these sections of inferior shapes (hereinafter referred to as crops) cause yield loss in the end, which amounts to as much as about 5 to 6 percent of a total tonnage of slabs used. Consequently, making this plate plan view pattern rectangular to reduce crop loss plays an important role in improving plate yield.

Since such behavior of plastic deformation in the non-homogeneous region is caused by complex factors, theoretical or quantitative analysis is considered difficult. So far, no attempts are made to conduct such analysis.

As a means of measuring plastic deformation in the non-homogeneous region, the authors have developed a composite picture method, thus making it possible to measure[1] plan view pattern changes. The result of such measurement is analized and equations for predicting plan view patterns are obtained[2,3,6]. This equation provided a basis for developing a new rolling process (Mizushima Automatic Plan View Pattern Control System hereinafter referred to as the MAS Rolling Process), which controls plate plan view patterns and attains an increased degree of rectangularity[4~6].

This paper reports the application of this technique to No. 2 Plate Mill of the Mizushima Works, which has been worked into the standardizing operational procedure with a remarkable success.

2 Behavior of Plan View Patterns in Plate Rolling

Plate rolling process is roughly divided into the following three stages.

Stage 1 (sizing rolling): In this initial stage, a slab is rolled in the longitudinal direction for 1 to 4 passes in order to eliminate the effects of slab surface conditioning, to produce an accurate slab thickness, and to improve the width accuracy of rolled plate in the next broadside rolling.

Stage 2 (broadside rolling): To obtain a required rolled width, the slab is turned around 90 degrees and rolled in the transverse direction.

Stage 3 (finishing rolling): Again, the slab is turned

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* Originally made public at AISE 1979 Annual Convention in Cleveland, Ohio

** Mizushima Works

around 90 degrees and rolled in the longitudinal direction to a required plate thickness.

Non-homogeneous plastic deformation becomes notable mainly when the rolled slab is still thick, namely, during the stages of sizing rolling and broadside rolling which produce a complex plan view pattern when the rolling is completed.

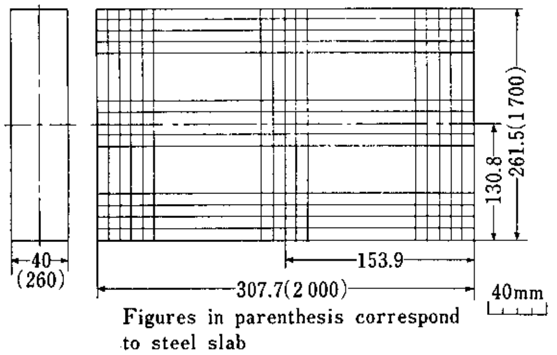


Fig. 1 Model slab dimensions and marking-off line to investigate deformation of plasticine

2.1 Basic Research by a Model Mill

In order to investigate the behavior of the plan view pattern of a rolled slab, a model mill was used to roll plasticine. The roll diameter and roll width of the model mill were 1/6.5 of the actual mill and plasticine slabs were also 1/6.5 of the actual standard slab size. Rolling was performed at room temperature (20 °C) and $CaCO_3$ powder was used as lubricant between the rolls and plasticine to create the hot rolling condition. Plasticine dimensions used and the positions of markings to investigate surface deformation are shown in **Fig. 1**. Also, the plan view patterns of plasticine upon completion of rolling are shown in **Photos. 1** and **2.**

(1) **Photo. 1** presents the case of performing no broadside rolling. Patterns of the leading and tail ends are such that the central portion is protruding more than both ends in the transverse direction. In other words, this is what is called the convex crop pattern. The side crops are, on

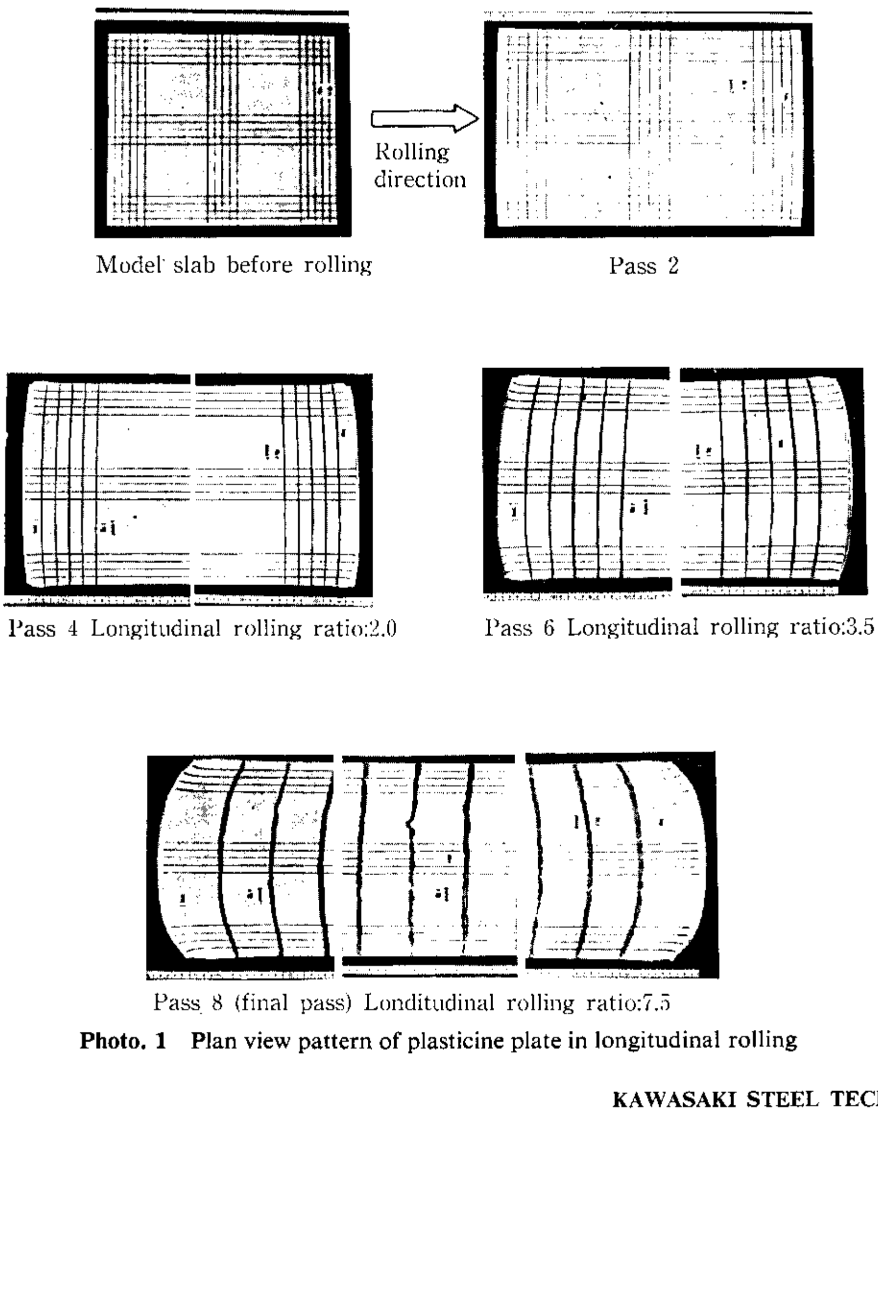


Photo. 1 Plan view pattern of plasticine plate in longitudinal rolling

the contrary, in spool shape, in which both ends protrude as compared with the central portion.

(2) Broadside rolling at the broadside rolling ratio (rolling width/slab width) of 2.0 is shown in **Photo. 2**. The shape of convex crops on the leading and tail ends in the longitudinal direction is improved as compared with (1) and the side crops shifted from spool to barrel shape.

In this manner, the result of the plasticine experiment has shown that the plan view pattern changes variously in combination with the longitudinal rolling ratio (rolling length/slab length) and the broadside rolling ratio, which agrees to the empirical trends in rolling at the actual mill.

2.2 Quantitative Analysis by the Composite Picture Method

For the effective rectangularity of the plan view plate pattern upon completion of rolling, it is essential to grasp quantitatively the plan view pattern in the rolling process for accurate prediction. Nevertheless, plate is hot-rolled by running the mill back and fouth. To measure the behavior of pattern deformation quantitatively during such process is a formidable task. After numerous tests, the authors developed a new method of measuring called the composite picture method. This enabled a quantitative determination of

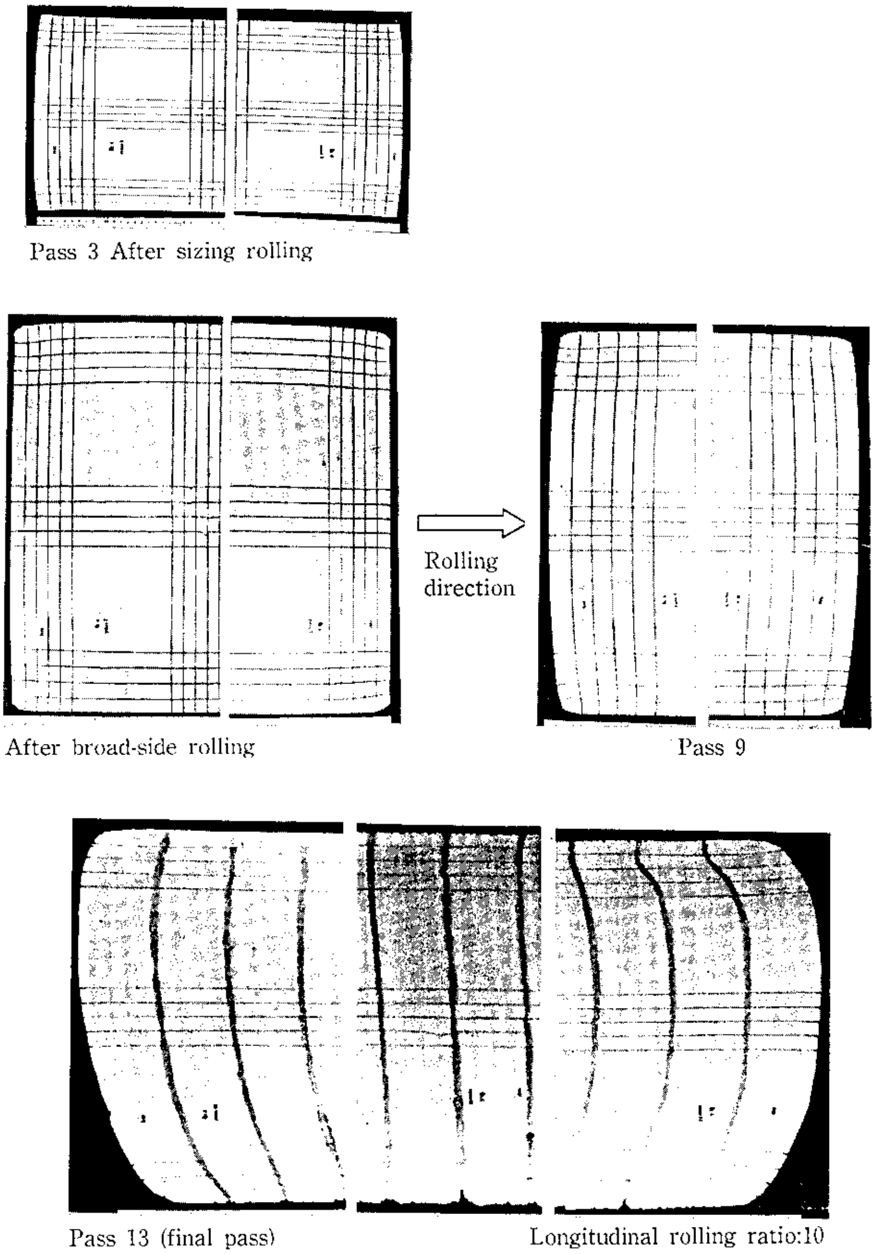


Photo. 2 Plan view pattern of plasticine plate at broad-side rolling ratio of 2.0

the plan view pattern change for each rolling pass and to discover the relation between the non-homogeneous plastic deformation and rolling conditions.

2.2.1 Principle of the composite picture method[1)]

A schematic presentation of the principle of this method is made in **Fig. 2**. Cameras were fixed above the roller table before and behind the plate mill and composite pictures to determine the plan view pattern were made as follows.

(1) To photograph a scale plate set on the roller table
(2) To photograph the slab to be rolled
(3) To combine the negatives of the scale plate and the slab

Examples of composite pictures obtained in this procedure are shown in **Photo. 3**. The dimensions from the photographed scale plate are read and the actual pattern of the slab is known by calculation for the reduced scale. At this point, errors due to the thickness of the slab, aberration of the lenses, negative composition and other factors are produced. However, in this experiment, the total errors were ± 8.3 mm at maximum, which is practically in allowable torelance.

2.2.2 Changes of plan view pattern in sizing rolling[2)]

Based on the result of the plasticine experiment, test materials as shown in **Table 1** were selected and their plan view pattern change for each pass was

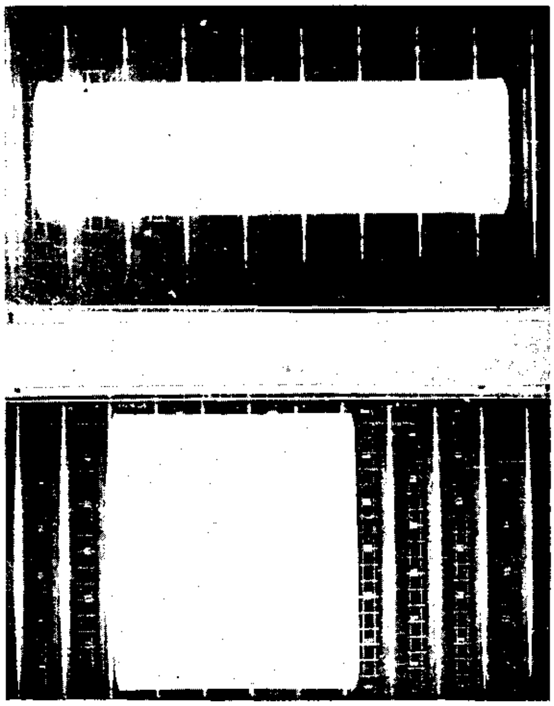
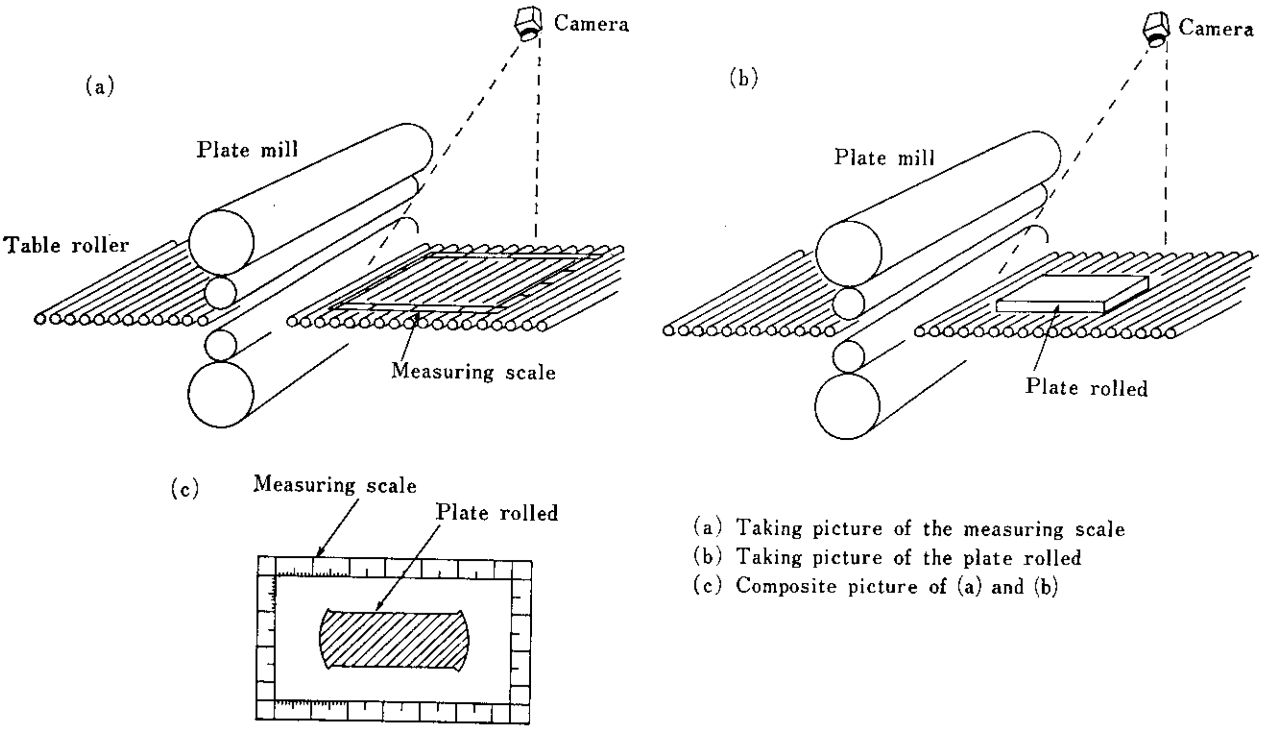


Photo. 3 Examples of composite picture



(a) Taking picture of the measuring scale
(b) Taking picture of the plate rolled
(c) Composite picture of (a) and (b)

Fig. 2 Method of composite picture to quantitatively study the behavior of plate deformation during rolling

Table 1 Specification of test materials to study the plan view pattern of each pass during rolling

No.	Slab dimension [mm]			Plate dimension [mm]			broadside rolling ratio	Longitudinal rolling ratio
	Thickness	Width	Length	Thickness	Width	Length		
1-4	215 ×	1575 ×	2889	16.00 ×	1524 ×	36576	0.97	12.66
5-8	215 ×	1575 ×	3021	16.00 ×	2434 ×	24380	1.55	8.07
9-12	215 ×	1575 ×	2844	16.00 ×	3048 ×	18288	1.94	6.43
13-16	215 ×	1575 ×	2889	16.00 ×	4572 ×	12192	2.94	4.22

measured. The test materials were rolled at No. 2 Plate Mill of the Mizushima Works. The results of plan view pattern in sizing rolling are the same as the one of the plasticine experiment: the leading and tail ends of plates take the barrel shape as shown in **Fig. 3** (a). Relation between the patterns of portions A and B, and the rolling conditions is as follows.

(1) Portion A pattern (spool pattern in the width direction) Amounts $f_1(x)$ of plan view pattern changes of portion A is calculated by equation **(1)**.

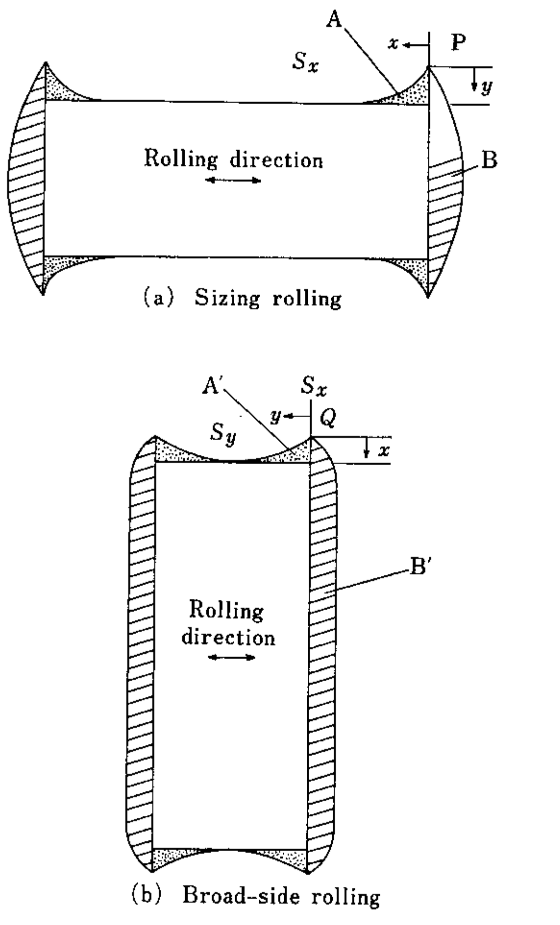


Fig. 3 Plan view pattern after sizing and broadside rolling

$$f_1(x) = a_0 + a_1x + a_2x^2 \quad \cdots\cdots\cdots\cdots \textbf{(1)}$$

$a_0 \sim a_2$ are constants determined by $\sum l_d \cdot r$ here (l_d: length of arc of contact, r: reduction ratio). As is clear from **Fig. 4**, which illustrates the results calculated by equation **(1)**, the spool pattern of portion A increases as $\sum l_d \cdot r$ rises.

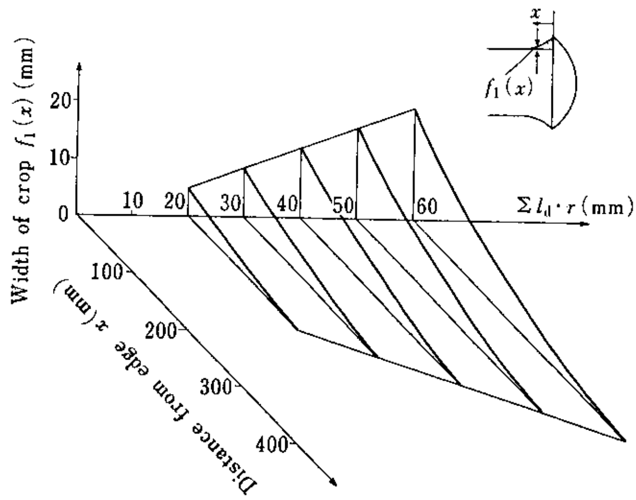


Fig. 4 Side crop shape in transverse direction after sizing rolling

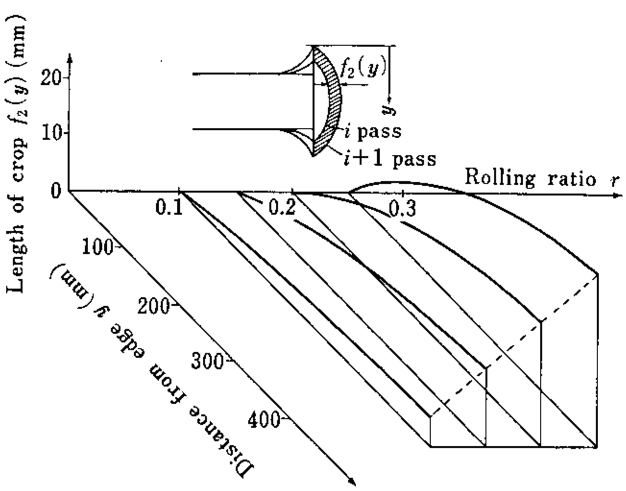


Fig. 5 Top and bottom crop shape in longitudinal direction at sizing rolling

(2) Portion B pattern (convex crop pattern at the leading and tail ends) Amout of $f_2(y)$ of plan view pattern changes of portion B is calculated by equation **(2)**.

$$f_2(y) = c_0 + c_1 y + c_2 y^2 \quad \cdots\cdots\cdots\cdots (2)$$

$c_0 \sim c_2$ are constants determined by r here.
Results calculated by equation **(2)** are shown in **Fig. 5**.

2.2.3 Plan view pattern changes in broadside rolling[3)]

As in the case of sizing rolling, broadside rolling also results in the barrel shape on the leading and tail ends of the plate as shown in **Fig. 3** (b). The relation between this pattern and rolling conditions can be expressed by equations **(3)** and **(4)**. Results of calculation are presented in **Figs. 6** and **7**.

$$f_3(x) = \frac{x}{b_0 + b_1 x} \quad \cdots\cdots\cdots\cdots\cdots\cdots (3)$$

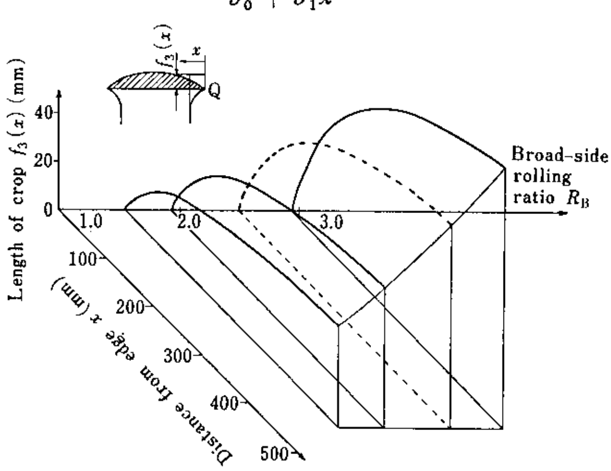


Fig. 6 Top and bottom crop shape in longitudinal direction after broadside rolling

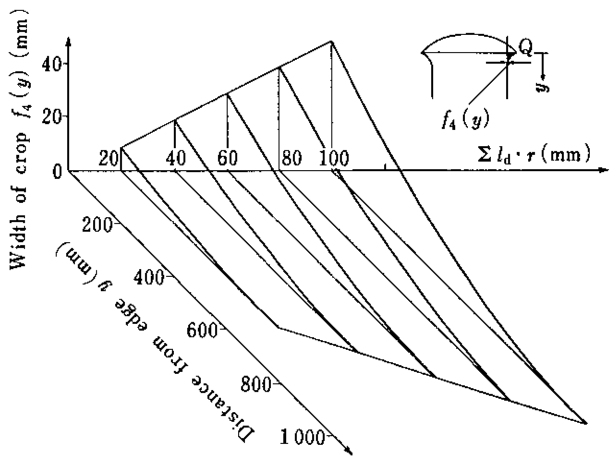


Fig. 7 Side crop shape in transverse direction after broadside rolling

$f_3(x)$: Amount of plan view pattern of portion B′
b_0 and b_1: Constants determined by the broadside rolling ratio.

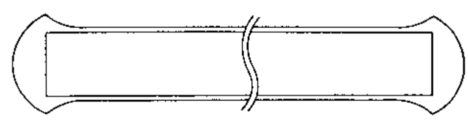
$$f_4(y) = d_0 + d_1 y + d_2 y^2 \quad \cdots\cdots\cdots\cdots (4)$$

$f_4(y)$: Amount of plan view pattern of portion A′
$d_0 \sim d_2$: Constants determined by $\sum l_d \cdot r$

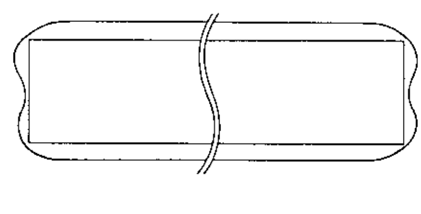
2.3 Notes on Plan View Pattern Changes

From the results of equation **(1)** through equation **(4)**, changes of the plan view pattern in sizing and broadside rolling have the same tendency basically. When the plate thickness is heavy and the rolling length is relatively finite as in the case of plate rolling, non-homogeneous plastic deformation occurs to a significant extent on the edges both in the longitudinal and width directions. Portions A and A′ in **Fig. 3** were generated as a width spread in this region expanded partially due to the end effect. On the other hand, portions B and B′ have a larger width spread than the central portion, because both edges in the width direction are free. This difference in width spread becomes a difference in elongation in the longitudinal direction and the portions B and B′ are produced. This tendency is considered to become obvious by the effect of a local width spread of portions A and A′.

Consequently, it can be said that the plate plan view pattern upon completion of rolling is virtually determined by the slab dimensions, rolling dimensions, and factors affecting width spread (for examples, reduction ratio, projected roll contact length, etc.). In other words, if the broadside rolling ratio is small



(a) In the case of less rolling ratio of R_B and greater one of R_R



(b) In the case of greater rolling ratio of R_B and less one of R_R

Fig. 8 Plan view pattern of as rolled plate while the longitudinal rolling ratio is large, the effects of A and B in **Fig. 3** remain until the completion of rolling. Crops in the leading and tail ends in the longitudinal direction take the convex shape, while side crops are in spool shape. Conversely, if the broadside rolling ratio is large while the longitudinal rolling ratio is small, the effects of portion A′ and B′ at the time of broadside rolling grow large. When the rolling is finished, crops in the leading and tail ends become concave and side crops are in barrel shape. This is shown in **Fig. 8**.

3 Plan View Pattern Prediction Model

As explained in the previous section, plate plan view patterns upon completion of rolling are produced as a compined result of patterns created in each pass of sizing rolling, broadside rolling, and finishing rolling. Based on equations **(1)** through **(4)** in the previous section, the rolling schedule, rolling dimensions, slab dimensions and other factors are taken into consideration to introduce an exact plan view pattern prediction model.

3.1 Side Crop Prediction Model

Function $F(X)$ expressing side crops can be represented by equations **(5)** on the basis of equations **(1)** and **(3)**.

$$F(X) = F(\alpha \cdot x) = f_1(x) + f_3(x) + \lambda \cdot f_1(\alpha x) \quad \cdots\cdots\cdots\cdots\cdots (5)$$

x: Distance in longitudinal direction at completion of rolling
α: Longitudinal rolling ratio in finishing rolling
λ: Correction factor in finishing rolling

As equation **(5)** is conducted from compounding equations **(1)** and **(3)**, which are obtained by regression analysis, owing to get high accuracy, side crop prediction model $T(X)$ is obtained by another regression analysis of steady state.

$$T(X) = \frac{T_C}{F(X_C)} F(X) \quad \cdots\cdots\cdots\cdots\cdots (6)$$

X_C: Center position in the longitudinal direction at completion of rolling

Function T_C expressing side crops can be represented by equation **(7)** as a difference between the amount of barrel U_B produced in broadside rolling, which corresponds to the position in the longitudinal direction, and the amount of V_B in the leading and tail ends created by longitudinal rolling.

$$T_C = K(U_B - V_B) + L \quad \cdots\cdots\cdots\cdots (7)$$

K and L: Constants determined by slab dimensions

In regard to U_B and V_B, various parameters of the rolling condition were used for regression analysis and equations **(8)** and **(9)** were obtained.

$$U_B = l_0 + l_1 R_B^{m_1} + l_2 \left(\frac{R_R}{R_B}\right)^{m_2} + l_3\, \Delta H_B^{m_3} \quad \cdots\cdots\cdots\cdots\cdots\cdots (8)$$

$$V_B = l_4 + l_5 R_R^{m_4} + l_6 \left(\frac{R_R}{R_B}\right)^{m_5} + l_7\, \Delta H_S^{m_6} + l_8\, \Delta H_F^{m_7} \quad \cdots\cdots\cdots (9)$$

R_B: Broadside rolling ratio
R_R: Longitudinal rolling ratio
ΔH_S: Sizing rolling reduction
ΔH_B: Broadside rolling reduction
ΔH_F: Finishing rolling reduction
l_i, m_i: Constants

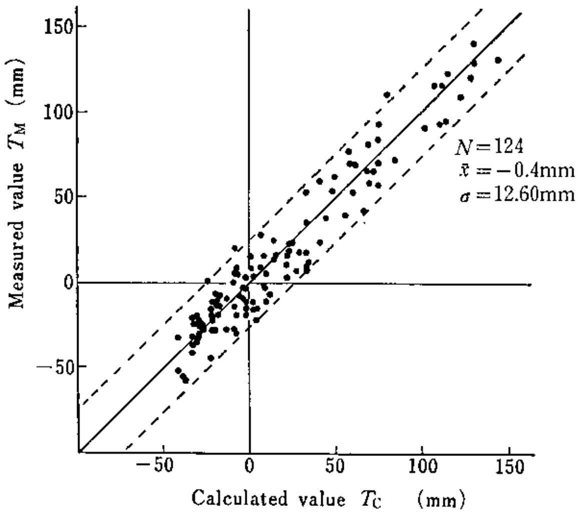


Fig. 9 Comparison of calculated and measured values of convex shape in the transverse direction

Fig. 9 shows a comparison of the amount of side crops T_C at the central position in the longitudinal direction obtained from this prediction model with the amount of side crops T_M measured after the rolled plates were cooled. Accuracy of this simplified model formulated for control is $\bar{x} = -0.4$ mm and $\sigma = 12.6$ mm, which are sufficient for practical use.

3.2 The Top and Bottom Crop Prediction Model

Function $G(Y)$ expressing the top and bottom crop can be represented by equation **(10)** on the basis of equations **(2)** and **(4)**.

$$G(Y) = G(R_B \cdot y) = \alpha \frac{1}{h_m} \sum_{i=1}^{m-1} h_i f_2(y)_i + \alpha f_4(R_B \cdot y) + \mu \frac{1}{h_n} \sum_{j=1}^{n} h_j f_2(R_B \cdot y)_j \cdots\cdots (10)$$

y: Distance in transverse direction
R_B: Broadside rolling ratio
h_m, h_n: Thickness
μ: Correction factor in finishing rolling
$i = 1 \sim m$: Pass number in sizing rolling
$j = 1 \sim n$: Pass number in finishing rolling

As equation **(10)** is obtained by combining equations **(2)** and **(4)**, which are obtained by regression analysis for high accuracy, the top and bottom crop prediction model $L_{CP}(Y)$ is obtained by another repression analysis. $L_{CP}(Y)$ will be as follows.

$$L_{CP}(Y) = \frac{L_{CPC}}{G(Y_C)} G(Y) \quad \cdots\cdots\cdots\cdots (11)$$

Y_C: Center position in the transverse direction after completion of rolling

Function L_{CPC} showing top and bottom crops can be expressed by equation **(12)** as a difference between the amount of convex crops U_C created by longitudinal rolling and the amount of V_C generated by broadside rolling.

$$L_{CPC} = M(U_C - V_C) + N \qquad (12)$$

M and N: Constants determined by slab dimensions

Also, in regard to U_C and V_C, various parameters of rolling conditions were used for regression and equations **(13)** and **(14)** were obtained.

$$U_C = g_0 + g_1 R_B^{k_1} + g_2 \left(\frac{R_R}{R_B}\right)^{k_2} + g_3 \Delta H_S^{k_3} + g_4 \Delta H_F^{k_4} \quad \cdots\cdots (13)$$

$$V_C = g_5 + g_6 R_R^{k_5} + g_7 \left(\frac{R_R}{R_B}\right)^{k_6} + g_8 \Delta H_B^{k_7} \quad \cdots\cdots\cdots\cdots\cdots\cdots (14)$$

g_i and k_i: Constants

Accuracy of this prediction model is also sufficient for practical use as shown in **Fig. 10**.

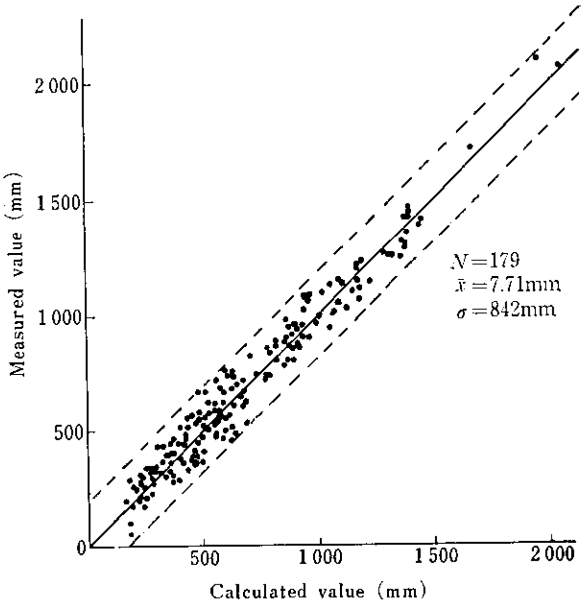


Fig. 10 Comparison of calculated and measured length of top and bottom crop at the center portion

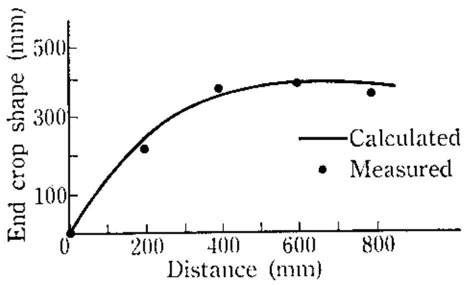


Fig. 11 End crop shape after completion of rolling

Fig. 11 shows the comparison the calculation result of plate plan view pattern upon completion of rolling which was obtained by equations **(6)** and **(11)** and measured one.

4 MAS Rolling Method

To improve inferior shapes due to non-homogeneous plastic deformation in rolling, the following methods have been employed with some success:

(1) Application of the draft schedule to control partial large width spread in sizing and broadside rolling.
(2) Improvement of convex crops by making the slab widthwise cross section concave[7)].
(3) Improvement of convex crops by making work-rolls or back-up rolls concave crown.

Any of these methods cannot meet all slab dimensions and rolling dimensions. It can be said that these methods are only for reducing inferior shapes on an average.

On the basis of the plan view pattern prediction model discussed in the previous section, we have established a new method of plan view pattern control (The MAS Rolling Method) which can deal with each slab accurately.

4.1 Principles of the MAS Rolling Method[4,6]

The principle of this rolling method consists in a quantitative prediction of the plate plan view pattern to be formed upon completion of rolling and in reducing in advance the volume of the portion equivalent to the predicted inferior pattern in order to prevent occurrences of inferior patterns and to get the plan view pattern closer to a rectangle.

The principle of the MAS rolling method to control side crops are shown in **Fig. 12**.

(1) From the prediction model of plate plan view pattern, the amount of inferior patterns is calculated and converted to a plate thickness difference at the final pass in sizing rolling.

(2) At the final pass in sizing rolling, the plate thickness difference is given to the position corresponding to the longitudinal direction.

(3) This plate thickness difference becomes a difference in the reduction ratio in broadside rolling and the plan view pattern is controlled.

Since the plate thickness controlling process is applied in the sizing rolling stage, this rolling for plate thickness modification is called the sizing MAS.

The amount of plate thickness modification can be obtained by equation **(15)** in accordance with the "volume conservation law".

$$\Delta h(x) = T(X)\frac{H}{W} \qquad \cdots\cdots\cdots\cdots(15)$$

$$X = \alpha x$$

$\Delta h(x)$: Amount of plate thickness modification at distance x in the longitudinal direction

$T(X)$: Side crops at distance X in the longitudinal direction upon completion of rolling

H: Final plate thickness

W: Slab width

When side crops are spool-shaped control will be made so as to make central portion thicker, contrary to **Fig. 12** (see **Fig. 13**). **Fig. 14** shows the principle of the MAS rolling method to control top and bottom crops. Since this method is implemented in the broadside rolling stage, it is called the broadside MAS rolling.

Likewise, the amount of thickness modification can be obtained from equation **(16)**.

$$\Delta h(y) = L_{CP}(Y)\cdot H/L' \qquad \cdots\cdots\cdots\cdots(16)$$

$$Y = \beta\cdot y$$

$\Delta h(y)$: Amount of thickness modification at distance y in the longitudinal direction

$L_{CP}(Y)$: Top and bottom crops at distance Y in the width direction after plate rolling is completed

L': Plate width in broadside rolling

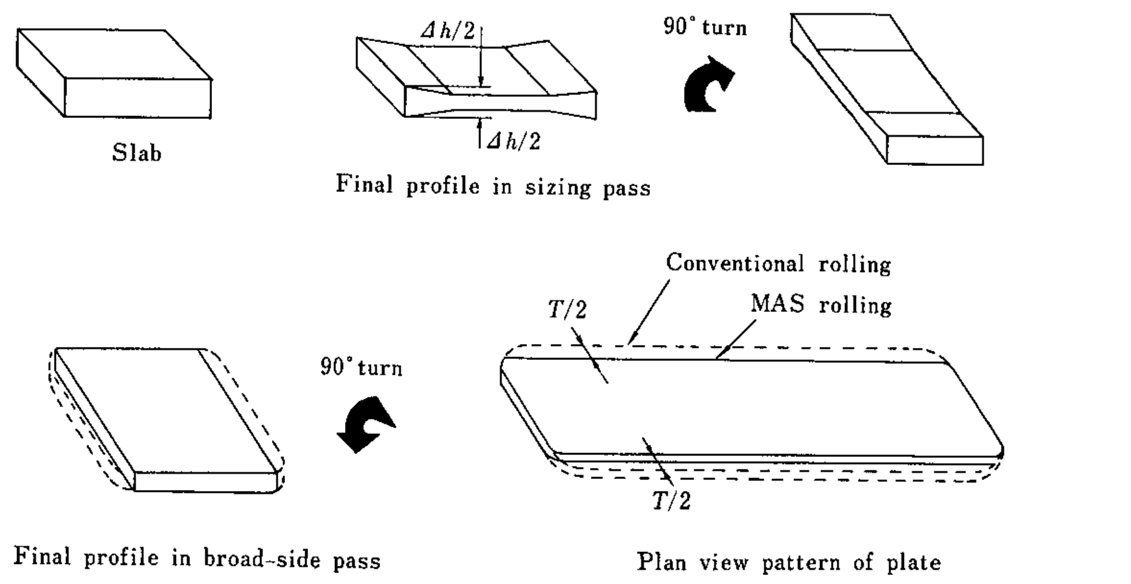


Fig. 12 Principle of sizing MAS rolling to control plan view pattern in transverse direction (1)

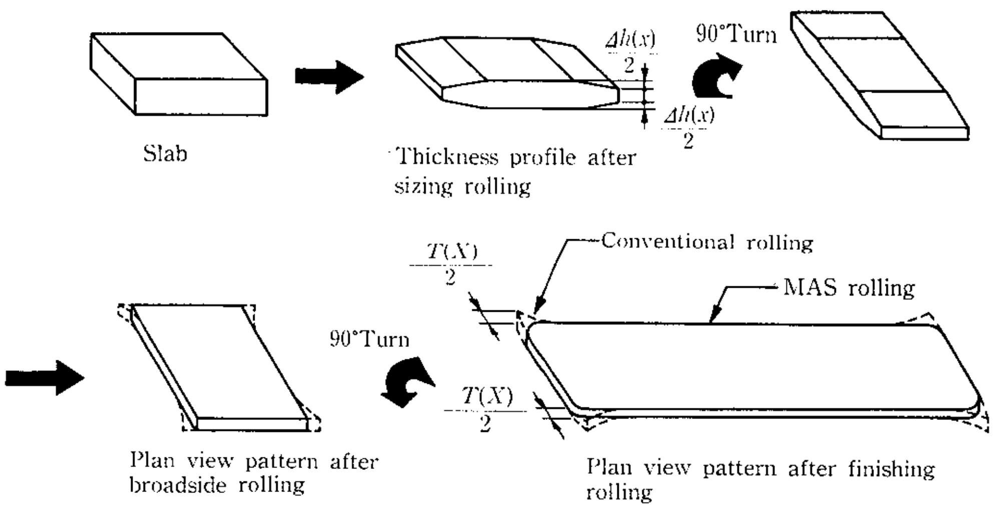


Fig. 13 Principle of sizing MAS rolling to control plan vew pattern in transverse direction (2)

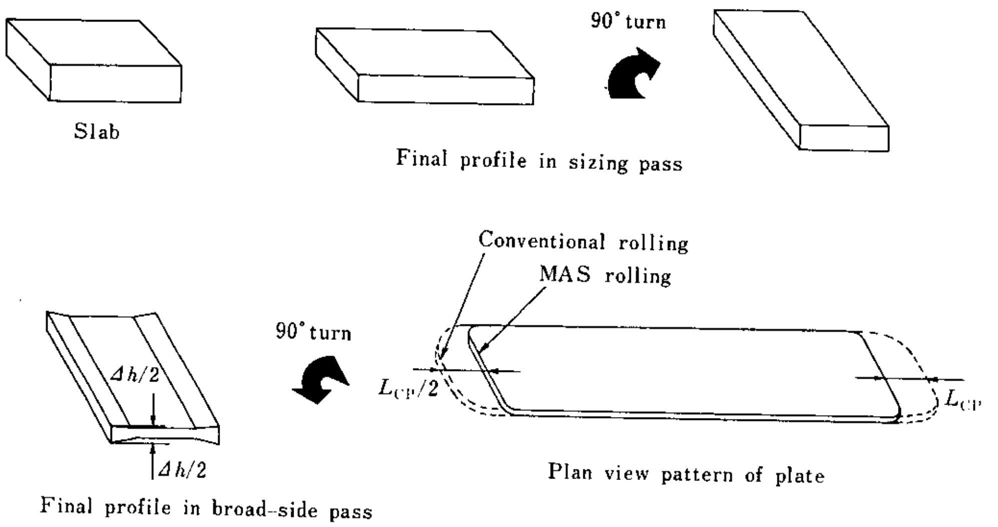


Fig. 14 Principle of broadside MAS rolling to control top and bottom crop

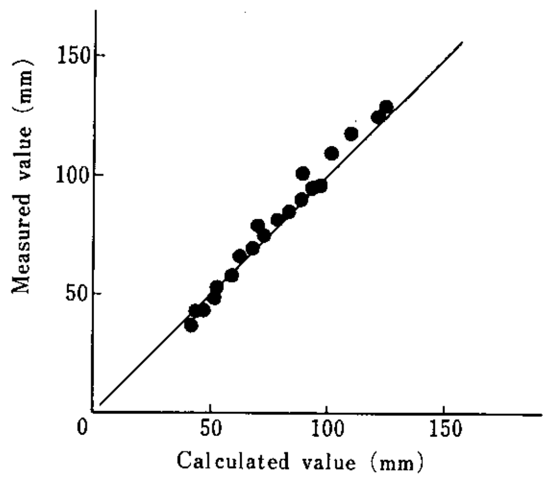


Fig. 15 Relation between calculated and measured values of convex shape in sizing MAS rolling using mechanical slab

β: Width spread ratio

In the event that crops are in concave shape, control made so as to make central portion thicker contrary to **Fig. 14**.

As we have seen, the principle of the MAS rolling method is to make use of the characteristics of plate rolling, which consist of sizing rolling, broadside rolling and finishing rolling, in order to control plan view patterns.

To confirm the accuracy of equations **(15)** and **(16)** obtained from the "volume conservation law", test rolling using machined slabs was performed. The relation between $T(X)$ obtained by substituting modified thickness amount $\Delta h(x)$ at each point in equation **(15)** and the measured values is shown in **Fig. 15**. Both values are in good agreement and adequacy of the method to determine the amount of thickness modification according the "volume conservation law" was confirmed.

4.2 MAS Rolling Control System[5)]

In applying the MAS rolling method for practical purposes, it is important to establish a highly accurate control system which will cause no discrepancy in thickness modification patterns and no excessive or deficient amount of thickness modification. In the thickness modification patterns shown in **Fig. 16**, it is necessary to control accurately modification amount $\Delta h(l_i)$, reduction completion point l_1 and reduction increase starting point l_i.

Fig. 17 shows the control system of the MAS rolling method. By means of the process computer ⑧, it computes the appropriate modification pattern, obtains reduction modification amount $\Delta S(l_i)$ from thickness modification amount $\Delta h(l)$ and further obtains roll speed R in consideration of the characteristics of the reduction position control system. Next, it determines the control points equivalent to l_1 and l_i in **Fig. 16** by considering the forward slip and links such information to the micro-controller ⑨.

The micro-controller gives instructions concerning the aimed control speed to the roll speed control system, and simultaneously with the biting of the slab, it gives instructions concerning the thickness modification amount and control positions.

Fig. 18 shows the flow chart of MAS rolling. Sizing MAS and broadside MAS are performed depending on the plan view pattern prediction model.

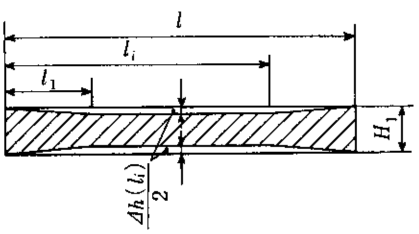
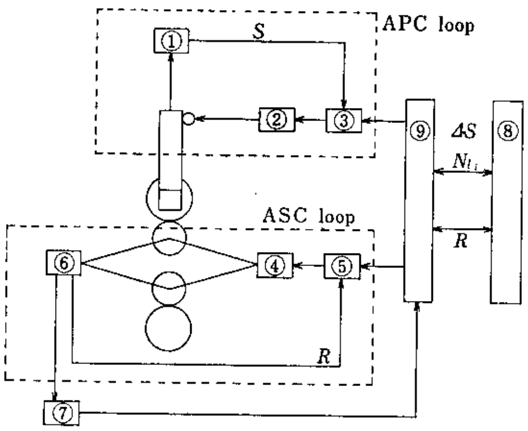


Fig. 16 Thickness profile on MAS rolling



① Screw position sensor
② Screw driving motor
③ Control device of screw position
④ Main motor
⑤ Control device of roll revolution speed
⑥ Roll revolution speed sensor
⑦ Pulse generator
⑧ Process computer
⑨ Micro controller

ΔS: Modification value of in screw position
N_{l_i}: Roll revolution pulse of turning point corresponding to l_i in Fig. 14
R: Roll revolution speed
S: Screw position
APC: Automatic position control
ASC: Automatic speed control

Fig. 17 Control system of MAS rolling

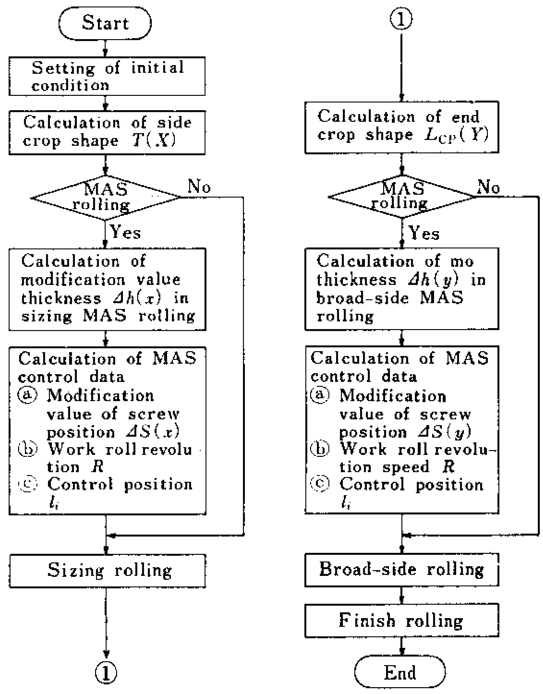


Fig. 18 The flow chart of MAS rolling

4.3 Control Accuracy

As mentioned above, the control system for sizing MAS and broadside MAS has been established by fully automatic computerized rolling. **Fig. 19** shows the test results of control accuracy in MAS rolling. **Fig. 19** (a), shows the result of measuring the longitudinal thickness of the slab which had been cooled immediately after sizing MAS rolling, which is in good agreement with the aimed values. This slab was reheated and rolled to its final thickness. Then its side crops were measured and compared with the result of the conventional rolling method. This comparison is shown in **Fig. 19** (b). By means of the MAS rolling method, the barrel shape was improved as required, making way to obtain the desired rectangularity.

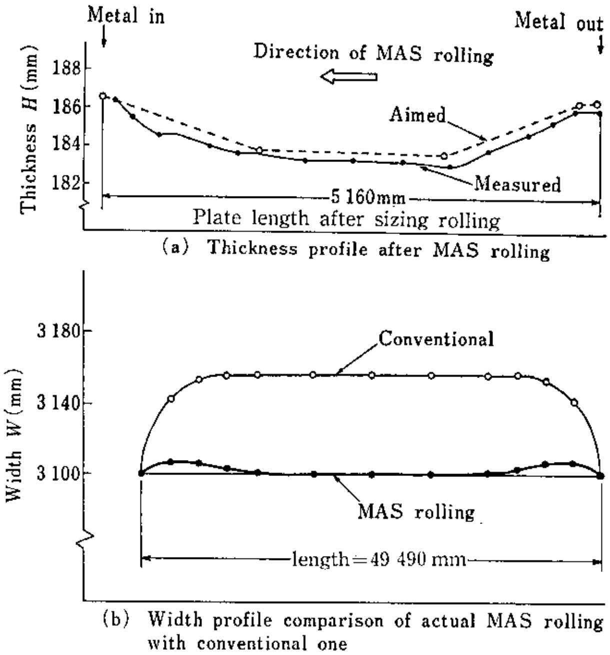


Fig. 19 An example of actual controlled data of MAS rolling

broadside rolling ratio of 1.5 was a boundary: the spool shape is produced below it and barrel shape above it. However, rectangularity of side crops is made by sizing MAS. Regardless of the broadside rolling ratio, side crop loss is nearly zero.

Fig. 21 shows the effects of improvement upon the top and bottom crops by broadside MAS rolling. With the parameter as R_R/R_B (longitudinal rolling ratio/broadside rolling ratio), average crop lengths are compared. Broadside MAS rolling results in controlling the top and bottom crops and reducing the average crop length largely.

Plan view patterns of the plates subjected to the MAS rolling method are shown in **Photo. 4**. For comparison, examples of side crops and top and bottom crops produced in conventional rolling are presented in **Photo. 5**. As is clear from these pictures, plan view patterns are well controlled and rectangularity is virtually attained by the MAS rolling method.

As shown in **Fig. 22**, the effects on yield are considerable. In conventional rolling, crop loss from the side and top and bottom was 5.5%, but it is down to 1.1% by the application of the MAS rolling method.

5 Results

In January, 1978, the MAS rolling method was taken up as a standing operational procedure at No. 2 Plate Mill of the Mizushima Works. Ever since then, it has been making remarkable contributions to yield improvement.

Fig. 20 shows the effects of improvement upon side crops by sizing MAS. In conventional rolling, the

6 Conclusions

Caused by non-homogeneous plastic deformation in plate rolling, crops loss is produced at the leading and tail ends in the longitudinal and transverse directions of plates. The authors measured the process of plastic deformation in rolling by the composite picture method and formulated the prediction model of plate plan view patterns. As a result, the new plan view

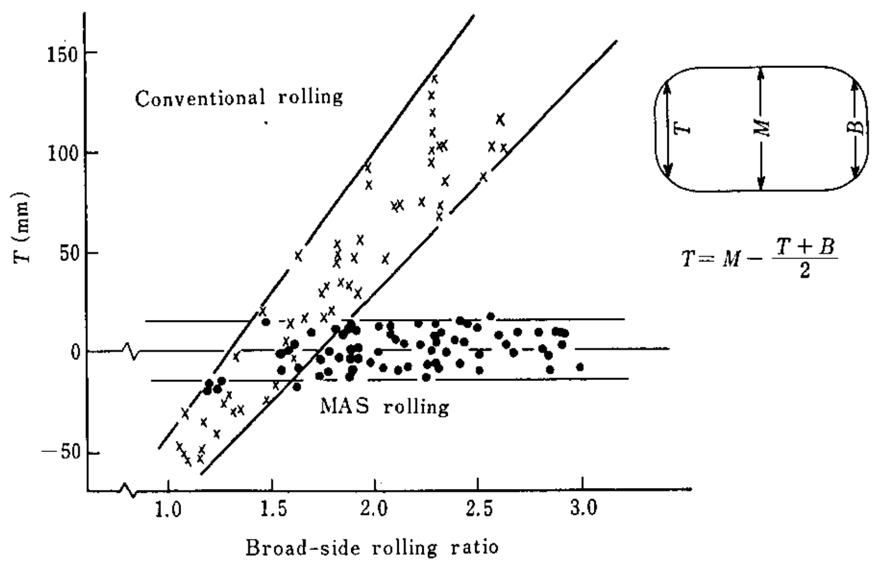


Fig. 20 Improvement of side crop shape through sizing MAS rolling

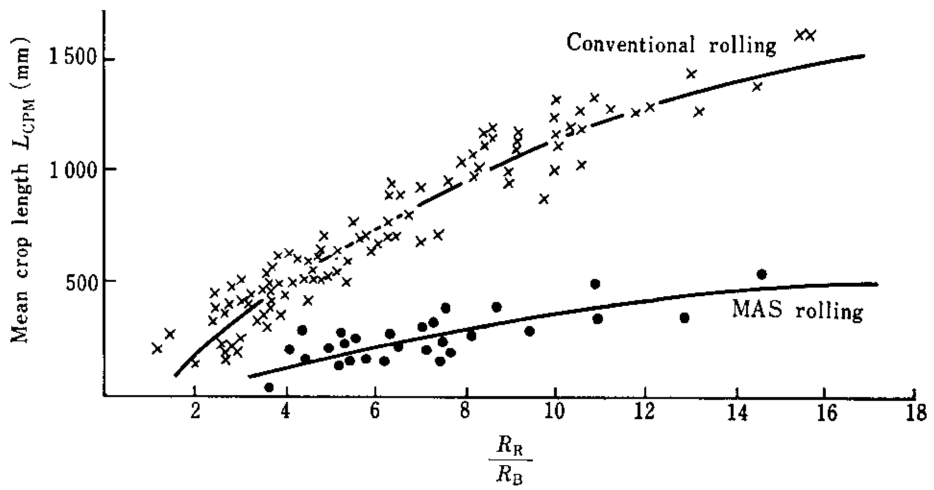


Fig. 21 Improvement of top and bottom crop shape through broadside MAS rolling

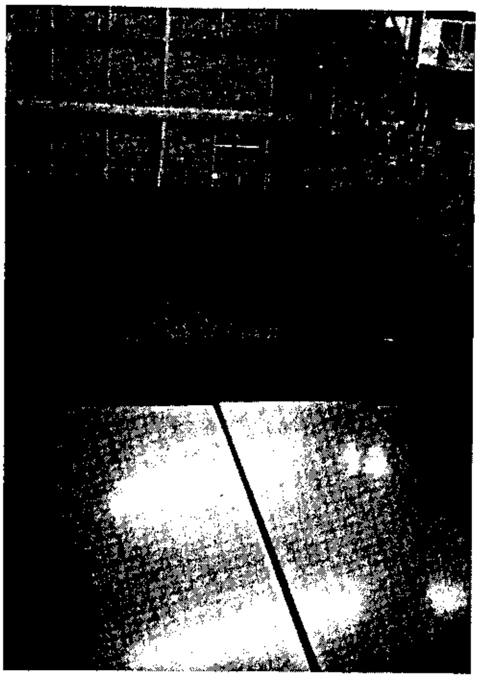


Photo. 4 Plate plan view pattern by MAS rolling

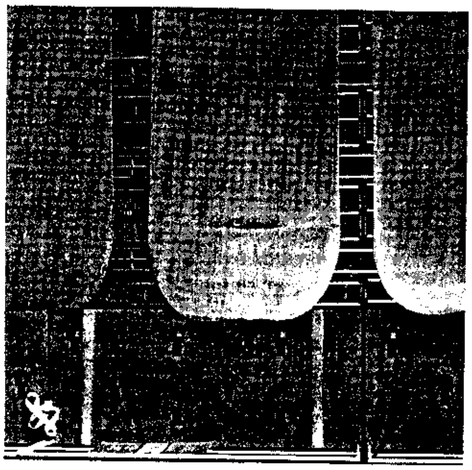


Photo. 5 Plate plan view pattern by conventional rolling

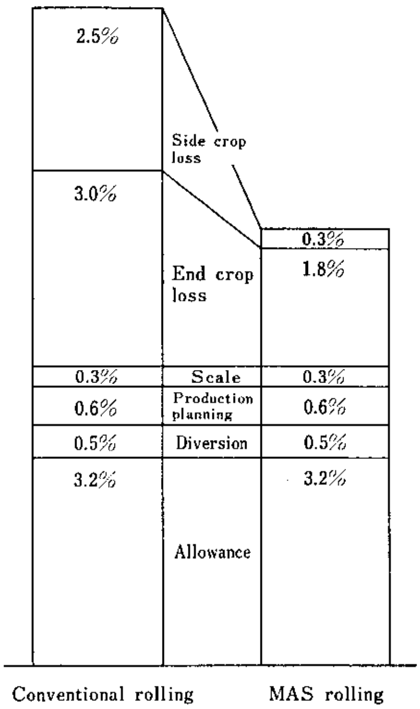


Fig. 22 Decreased loss through MAS rolling

pattern control method (The MAS rolling method) was developed as a success in making plate plan view patterns rectangular.

Plate-making engineers have been thinking of yield improvement through making plan view patterns rectangular. The authors came to grips with this subject and developed a new technique, the MAS rolling method.

It goes without saying that the MAS rolling method has greatly contributed to yield improvement. Also, it is no exaggeration to say that this rolling method, which is a breakthrough in conventional rolling, has paved the way for future technological development.

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