KAWASAKI STEEL TECHNICAL REPORT

No.25 (September 1991)

Special Issue on 'H-Shapes with

Fixed Outer Dimension' and 'Steel Pipe'

Development of Rolling Techniques to Control Outer Dimensions of H-Shapes

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The conventional universal rolling of H-shapes results in fixed inner dimensions that are governed by the roll sizes used. H-shapes produced by rolling to fixed outer dimensions are more desirable for productivity in construction work. Kawasaki Steel has developed new method for hot rolling steel H-shapes which can produce rolled H-shapes with as high quality as that of welded H-shapes. To control the outer dimension of web depth, it was found through an experimental model rolling that web width reduction by a universal mill can maintain the web depth constant for differing flange thickness. This rolling method prevents the occurence of web buckling, web off-centering and nonuniform web thickness, which are the main problems encountered in web width reduction. It was also found by model rolling experiments that grooveless edger roll were effective for controlling the flange width, which is the other outer dimension. These techniques have already been applied to the production of H-shapes, and the same quality for web off-centering and flange width as that of conventional products was obtained. These techniques have been able to produce a new type H-shape and also to realize a size-free rolling of H-shapes which is a main subject in the field of shape rolling.

1 Introduction

In the conventional universal rolling of H-beams, outer dimensions such as the web depth and flange width are governed by the flange thickness and web thickness due to constraints in the rolling equipment, the inner dimensions being fixed. The demand for H-beams from the construction industry has been increasing rapidly in recent years, and better on-site jointability results from fixed outer dimensions. Consequently, it is desirable for H-beams produced by hot rolling to have also fixed outer dimensions.

To obtain fixed outer dimensions for the web depth and flange width in the same H-beam series, it is necessary to introduce a new rolling function that can control these outer dimensions in the conventional rolling process.

Kawasaki Steel has already developed rolling techniques and equipment for controlling these outer dimensions. This has been made possible by using the inner web width reducing method with a universal rolling mill[1,2] to control the web depth, and the edger rolling method with grooveless rolls[3,4] to control the flange width. These methods have been put into practical use with great success. This report describes the development of these rolling methods and presents an outline of the techniques used.

* Originally published in *Kawasaki Steel Giho*, 23(1991)1, 16–22

2 Controlling the Web Depth

2.1 Problems with Web Depth Control and Their Solution

The web depth (H) of an H-beam is, as shown in **Fig. 1**, the total obtained by adding the flange thickness (t_f) on the two sides to the inner web width (B_W), and is given by Eq. (1):

$$H = 2 \times t_f + B_W \quad \cdots\cdots(1)$$

where H: web depth (mm)
t_f: flange thickness (mm)
B_W: inner web width (mm)

In the conventional rolling process, the inner web width of an H-beam is constrained by having to be equal to the fixed barrel length of the horizontal roll. The flange thickness (t_f) has various sizes, and the web depth (H) consequently changes depending on the flange thickness.

To produce H-beams to a fixed web depth (H) with varying flange thickness (t_f) without changing rolls, it is necessary to control the inner web width (B_W) according to the flange thickness.

The most critical aspect in the development of a technique for controlling the web depth is the choice of method to control this inner web width in an actual rolling process.

2.2 Examination of Rolling Methods

Conceivable methods for controlling the inner web width can be broadly categorized as involving web width enlargement and web width reduction. With the inner web width reducing method, the web depth of thin-section H-beams is used as the standard outer dimension, and thick-section H-beams are adjusted to this standard dimension. Therefore, the thicker the section, the greater the required deformation will be in web reduction. If this is done, the temperature of the rolled stock is higher than in thin-section H-beams, and deformation is, therefore, easier in thick-section H-beams. After studying this concept, the inner web width reducing method was examined.

Possible techniques for reducing the inner web width include (1) using a vertical rolling mill and (2) using a universal rolling mill. With both techniques, the occurrence of buckling is to be prevented, and a model rolling experiment using lead material was conducted[5] to quantify this problem.

2.2.1 Vertical rolling method

H-shapes of pure lead (99.99%) to a 1/6 scale of an actual H-beam were produced by extrusion, and an inner web width reducing experiment was carried out on a vertical rolling laboratory mill under the conditions given in **Table 1**. In this experiment, the central zone of the web was constrained at the roll center position by using two or three sleeve rollers as shown in **Fig. 2**. To investigate the effect of the constraining rollers on the constraint of buckling at the start of width reduction, rolling was done after shifting these rollers 40 mm towards the entry side. The cross sections of H-beams obtained by this rolling method are shown in **Fig. 3**. It is apparent that inner web width reduction by vertical rolls buckled the web between the sleeve rollers, resulting in an H-beam with a bad shape when the width reduction was large even though the rollers were used. It is also apparent that the rollers had no effect when

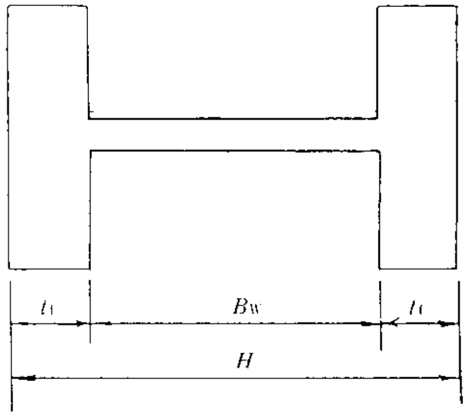

Fig. 1 Dimensions governing web depth in an H-beam

Table 1 Experimental conditions for vertical rolling

Material	Pure lead (99.99%)
Roll	S45C
Lubrication	No lubrication
Web inner width	80 mm
Flange width	30 mm
Web thickness	1.5~3.5 mm
Thickness ratio	1.5~2.0
Vertical mill	
Vertical roll	150 mmφ

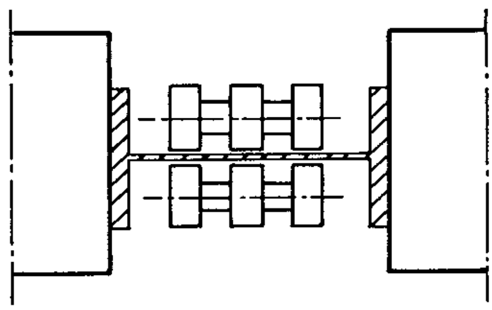
Fig. 2 Reduction method for web inner width with a vertical rolling mill

Roller Shift ΔS*	$\frac{\Delta B_W}{T_W}$	Cross section
2 rollers $\Delta S = 0$ mm	1.5	
3 rollers $\Delta S = 0$ mm	1.5	
3 rollers $\Delta S = 40$ mm	0.75	

*ΔS: Distance from the roll center 10 mm

Fig. 3 Cross sections of H-beam after experimental vertical rolling

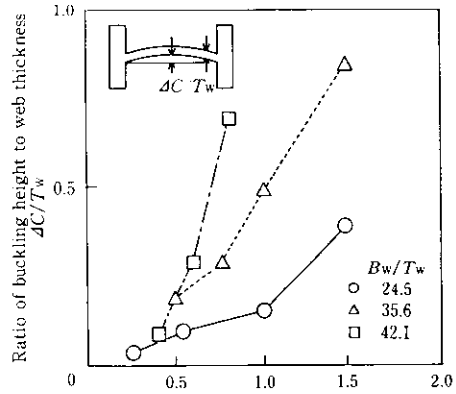

Fig. 4 Relationship between buckling shape ratio and web width reduction ratio in the case of vertical rolling

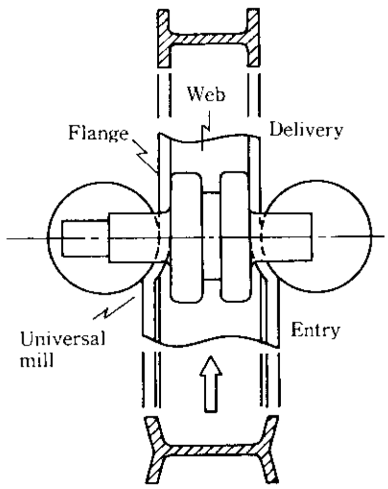

Fig. 5 Reduction method for web inner width with a universal mill

there was no constraint at the roll center, even if the onset of buckling at the beginning of contact was prevented by shifting the rollers closer to the entry side.

Figure 4 shows the relationship between the ratio of the buckling displacement of the web after reduction to the web thickness (buckling shape ratio) and the ratio of the reduction of inner web width to the web thickness (width reduction ratio).

If the buckling shape ratio is to be limited to 0.2 or less from the web displacement tolerance in accordance with JIS (Japanese Industrial Standard), then the maximum width reduction ratio is about 0.5 with the vertical rolling method, even if sleeve rollers to prevent buckling are used.

In other words, only an inner web width equal to the web thickness multiplied by 0.5 or less can be changed by the vertical rolling method, and hence, the width adjustment provided by the vertical rolling method is not adequate.

2.2.2 Universal rolling method

Inner web width reduction by a universal rolling mill is more advantageous than that by the vertical rolling method in that flange thickness reduction can be performed at the same time as the reduction of the inner web width.

Reduction of the inner web width by a universal rolling mill is shown in **Fig. 5**. To reduce the flange thickness by this method without roll changing, it is necessary to use width-adjustable sleeve rolls.

To evaluate this method, an inner web width reduction experiment was conducted on a universal rolling mill provided with width-adjustable sleeve rolls under the conditions given in **Table 2**. The width-adjustable roll consists of two sleeve rolls of 31-mm barrel length on one side. Because the web does not come into contact with the center portion of this roll, a buckled shape may sometimes remain after rolling.

In the same manner as in the vertical rolling experiment, the relationship between the width reduction ratio and the buckling shape ratio for universal rolling is shown in **Fig. 6**. In this figure, distinction is drawn in terms of the reduction difference between the flange and the web; a case in which the flange was heavily reduced at reduction rates of 5% or more relative to the

Table 2 Experimental conditions for universal rolling

Material	Pure lead (99.99%)
Roll	S45C
Lubrication	No lubrication
Web inner width	80 mm
Flange width	30 mm
Web thickness	1.5~3.5 mm
Thickness ratio	1.5~2.0
Universal mill	
Horizontal roll	220 mmϕ
Vertical roll	150 mmϕ

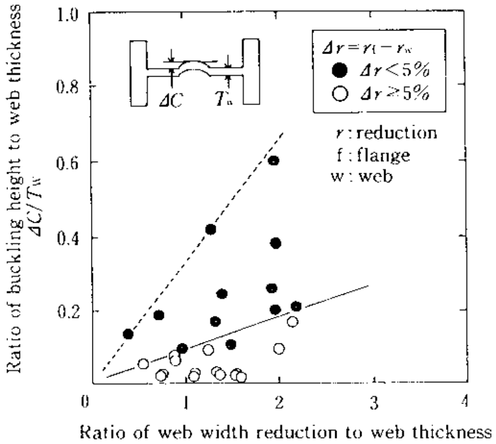

Fig. 6 Relationship between buckling shape ratio and web width reduction ratio in the case of universal rolling

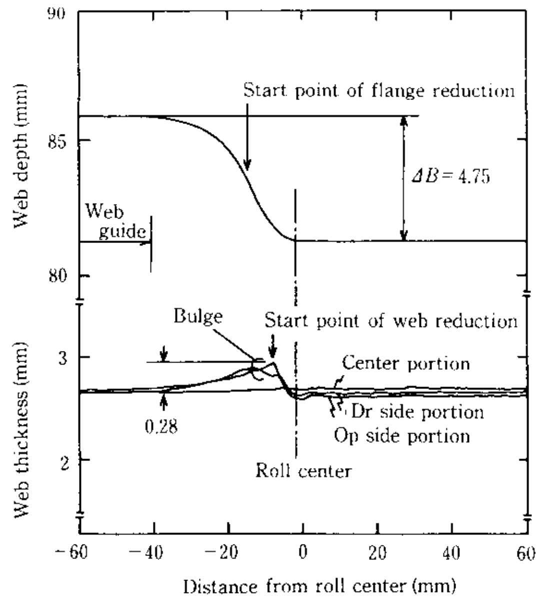

Fig. 7 Distribution of web thickness and web depth during web inner width reduction with a universal mill

web is indicated by an open circle (○), and a case in which the flange reduction rate was less than 5% is indicated by a solid circle (●). It is apparent from this figure that inner web width reduction by universal rolling allows a heavy reduction of the flange of 5% or more relative to the web with minimal buckling after rolling.

This effectiveness might stem from the reduction rate of the flange being higher than that of the web, which results in an increase in the elongation of the flange. If this is the case, the tension from the flange would work on the web to prevent buckling. The maximum value of width reduction ratio for heavy reduction of the flange was 2.0 by this rolling method. Thus, control of the width by this method is greater than that by the vertical rolling method.

Based on the foregoing results, it was decided to adopt the inner web width reduction method with a universal rolling mill to control the web depth.

2.3 Characteristics of Inner Web Width Reduction by a Universal Rolling Mill

It might be thought that this rolling method produces rolling characteristics that are much different from those in conventional universal rolling. These characteristics were examined by conducting the same lead model rolling experiment as that in the previous section, and a hot steel experiment.

2.3.1 Dimensional distribution in the longitudinal direction

During the reduction of inner web width, the rotation of the rolls was stopped halfway through the length of the material to hold the material in the rolls, and the dimensional distribution of the web thickness and web depth in this material were measured in the longitudinal direction. The results of this measurement are shown in **Fig. 7**. During the experimental rolling, the web on the entry side was constrained by a friction guide. A decrease in the web height began from the end of the web guide, where the web inner side was a free surface. This position is very near the entry side compared with the position where the web depth can be reduced by a vertical roll. The web thickness was measured at three positions across the web; the thickness at the two ends of the web began to increase at the same time as the decrease in web depth as the arc length of contact with the sleeve rolls increased. This is similar to the dog-bone deformation observed during the width reduction of a plate. Because width-adjustable sleeve rolls were used, the central zone of the web was not in contact with the rolls. Under the rolling conditions shown in Fig. 7, however, no extreme plate thickness difference occurred.

2.3.2 Mean rolling pressure

The roll separating forces on the horizontal and

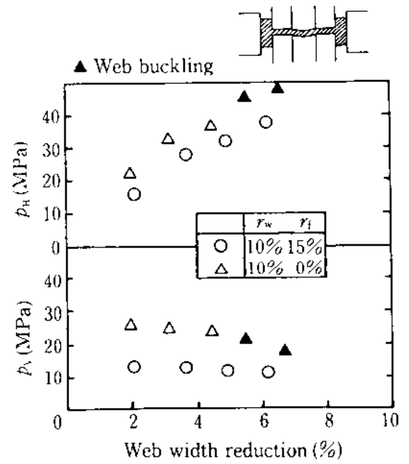

Fig. 8 Mean rolling pressure of horizontal roll, p_H and vertical roll, p_V

vertical rolls were measured with load cells, and the length of the projected arc of contact of the vertical roll was determined from the measured thickness values before and after rolling by the following equation:

$$L_{dBW} = \sqrt{2R_v \times \left(\Delta t_f + \frac{\Delta B_W}{2}\right)} \quad \cdots\cdots\cdots\cdot(2)$$

where L_{dBW}: Arc length of the vertical roll (mm)

R_V: Radius of the vertical roll (mm)

Δt_f: Flange thickness reduction (mm)

ΔB_W: Inner web width reduction (mm)

The mean rolling pressure is shown in **Fig. 8**, and it is apparent that the mean rolling pressure increased with increasing web inner width reduction, while the mean rolling pressure of the vertical rolls tended to decrease. In this figure, cases in which no reduction of flange thickness was done are indicated by an open triangle (△); in these cases, the load from the vertical rolls was the only force necessary for width reduction of the web, and a high mean rolling pressures resulted. Also shown are cases in which the inner web width was heavily reduced without reducing the flange thickness; these cases are indicated by a solid triangle (▲) in the figure.

When the reduction of the inner web width was large, the mean rolling pressure from the horizontal roll was high, even when the flange thickness was reduced. This is due to the effect of an increase in plate thickness at the outer ends of the web as described in the previous section.

2.3.3 Web off-centering

When the reduction of inner web width is excessive, the flanges can shift in the transverse direction on the entry side, causing off-centering of the web. As a result, either the web itself can deform or the flanges become displaced relative to the web, so that the shape enters the rolls in this condition.

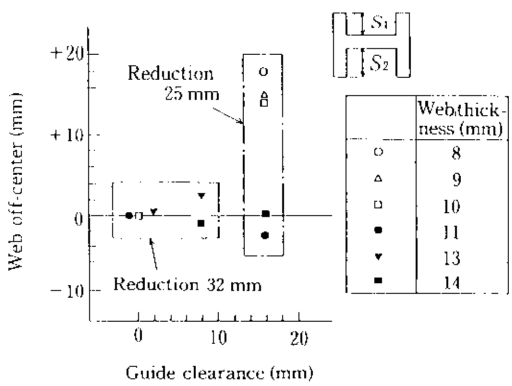

Fig. 9 Relationship between web off-center and web guide clearance

To prevent this problem, it was necessary to guide the web on the entry side close to the rolls and to prevent any transverse movement of the flange.

The effect of web guide clearance on the off-centering after rolling is shown in **Fig. 9**. It can be deduced from this figure that a clearance between the web surface and the web guide of less than 2 mm was effective in preventing web off-centering.

2.4 Results of Application to Production

Width-adjustable sleeve rolls were fitted to the finishing universal mill in the wide-flange beam mill at Mizushima Works, and commercial production of "Super HISLEND-H" with a fixed web depth was started in November 1989.

Photo 1 shows the cross sections of H-beams in three shapes of the H450 × 200 series. Although the flange thickness is different, the web depth is fixed and the outer dimensions are constant.

The results of measurements of the web depth in the

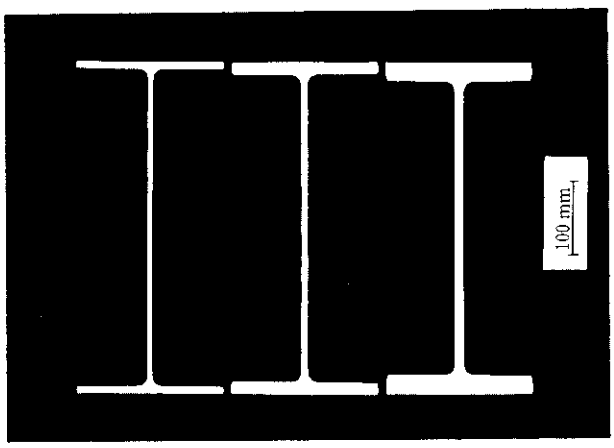

Photo 1 Cross sections of Super HISLEND-H 450 × 200 mm

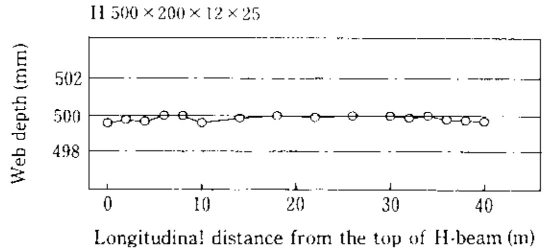

Fig. 10 Distribution of web depth in the longitudinal direction of H500 × 200 beam

longitudinal direction are shown in **Fig. 10**. The web depth is within the tolerance along the full length and accurate dimensions are maintained.

3 Controlling the Flange Width

3.1 Problems with Flange Width Control and Their Solution

As shown in **Fig. 11**, the flange width (B_f) of an H-beam is the sum of the upper and lower flange lengths (b) and the web thickness (t_W), and is given by Eq. (3):

$$B_f = t_W + 2b \quad \cdots\cdots(3)$$

where B_f: frange width (mm)
t_W: web thickness (mm)
b: flange length (mm)

With conventional edger rolling, grooved rolls are used as shown in **Fig. 12**. The grooves of the edger rolls are effective in reducing off-centering by controlling the upper and lower flange lengths.[6] However, because the groove depth of the edger rolls is fixed during rolling, the flange length is also fixed. Thus, with conventional rolling, the flange width (B_f) changes according to the web thickness (t_W) and the outer dimensions are not fixed.

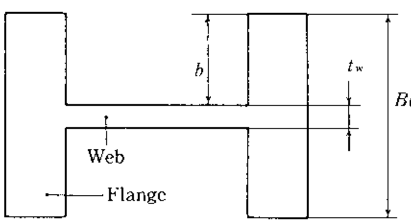

Fig. 11 Dimensions governing flange width in an H-beam

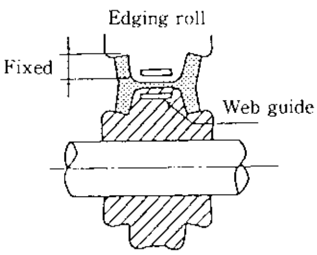

Fig. 12 Conventional edger rolling

To maintain a constant flange width, it is necessary to adjust the flange length (b) according to the web thickness.

To control the flange length without changing the edger rolls, the flange width is reduced by using grooveless edger rolls, and web off-centering is corrected by a universal rolling mill. By separating the operations in this manner, the flange length can be controlled in the universal rough rolling process.

3.2 Examination by a Model Experiment

3.2.1 Web off-centering correction by a universal mill

In the conventional rolling process, the stock is guided to a universal rolling mill with the web supported. Therefore, if the material before rolling has an off-centered web, it is rolled in this condition and the off-centering is not corrected.

It was considered that guiding the flange rather than the web to the universal rolling mill would be more effective in preventing web off-centering, and the equipment used, including the edger mill, is shown in **Fig. 13**. Features of this method are shown below.

(1) A flange-constraining roller guide, which guides the upper and lower flanges, is installed on the entry side of the universal rolling mill.
(2) A similar flange-constraining roller guide is also installed on the delivery side of the universal rolling mill, and at the same time, grooveless edger rolls are installed near the universal rolling mill, so that the material can be easily guided to this mill.

To ensure that web off-centering is prevented, the center portion of the flange is guided to the central gap of the horizontal rolls. Grooveless edger rolls were installed close to a universal rolling laboratory mill before the flange-constraining roller guide, and a lead

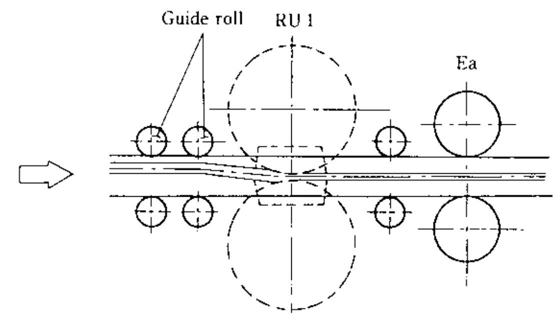

Fig. 13 New method for H-beam guiding

Table 3 Experimental conditions for grooveless edging

Material	Pure lead (99.99%)
Stock size (mm)	H55×30×3.0×3.5 H55×50×3.0×3.5
Universal mill reduction ratio	
Web	15%
Flange	16%
Edger mill reduction	2 and 4 mm

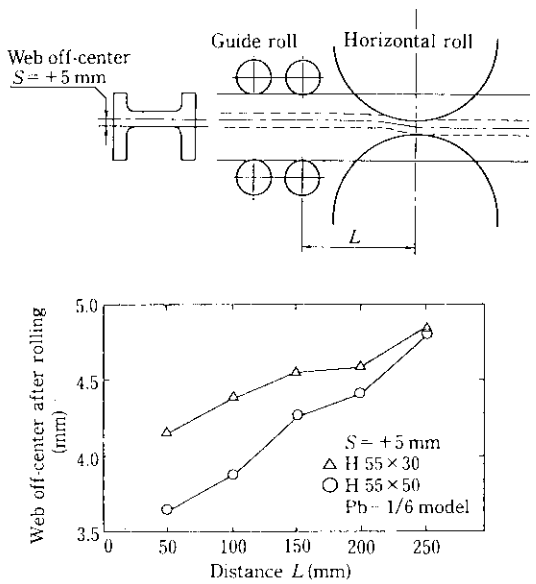

Fig. 14 Effect of flange guiding on the correction of web off-centering

model experiment was conducted under the conditions given in **Table 3**.[7]

In this experiment, H-shapes of two different flange widths and with web off-centering of +5 mm were used, and the change in off-centering was measured after rolling when the center-to-center distance between the roller and the roll was varied.

The results of the measurement of web off-centering in the rolled shapes are shown in **Fig. 14**. It is apparent that the larger the flange width of the shape and the higher the stiffness, the greater was the correcting effect for web off-centering, and that the shorter the center-to-center distance between the roller and the roll, the greater was this effect again. Therefore, this flange-end guiding method that constrains the flange externally on a universal rolling mill was effective in preventing web off-centering.

3.2.2 Examination of the grooveless edger rolling

With grooveless edger rolls, it is necessary to prevent flange buckling, etc. during flange width reduction.

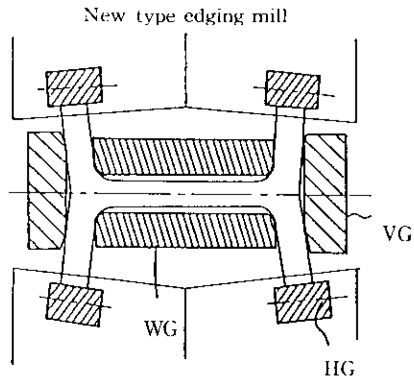

Fig. 15 Guiding system for grooveless edger rolling

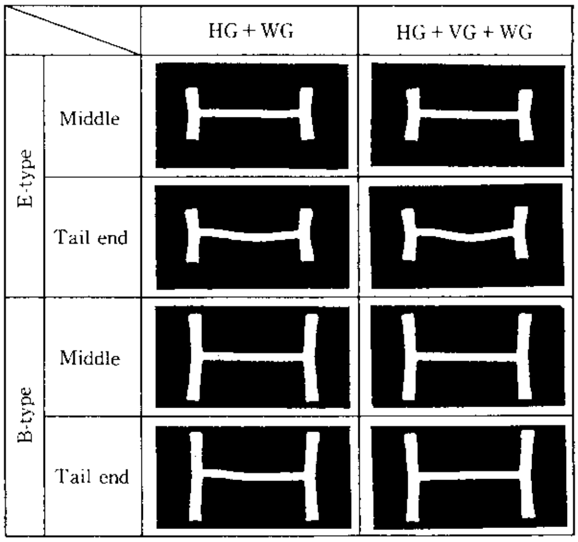

Fig. 16 Cross sections of H-beam after experimental grooveless edger rolling

To determine the necessary support for the flanges, therefore, a lead model experiment was conducted under the same conditions as those given in Table 3.

As shown in **Fig. 15**, upper and lower horizontal roller guides (HG) to guide the material to the edger, right and left vertical roller guides (VG), and web guides (WG) to prevent web off-centering might all be necessary to ensure stable rolling. For this reason, an examination was made of each of these devices to discover their effectiveness in holding the material during rolling.

Cross-sectional shapes of test pieces rolled by this new guiding method are shown in **Fig. 16**. It is apparent that flange buckling did not occur, at least in the mid-length of the shape, and that although slight web buckling occurred at the tail end with the guide combination of HG plus WG, flange buckling did not occur. Almost the same results were observed with the same guide combination plus VG. It was concluded from these results that VG was not necessary and that the HG plus WG combination was adequate.

3.3 Results of Application to Production

The equipment specifications were determined from the results of the model experiments, and the new control techniques were applied to a production process. In the newly developed equipment, the distance between the universal rough rolling mill and the edger mill was decreased from the conventional 5000 mm to 1890 mm, and adjustable-width guides make it unnecessary to change guides for each series of H-beams.

Figure 17 gives a comparison of the accuracy of web off-centering and flange width between the conventional rolling method and the newly developed method. Almost the same accuracy is apparent.

The adoption of this rolling method enables the flange width to be kept constant, and both the rolls and guides of the newly developed edger mill are size-free; therefore, a substantial decrease in the roll-changing time has been achieved, and the number of rolls required has been reduced as shown in **Table 4**.

H－500×200

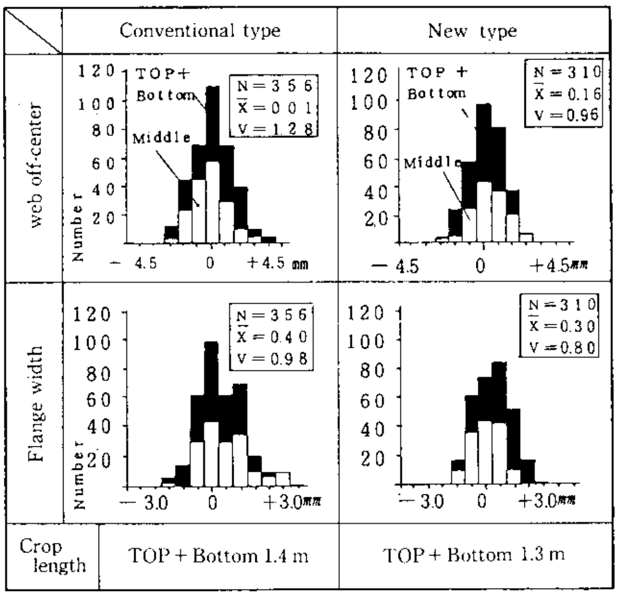

Fig. 17 Accuracy comparison of web off-centering and flange width between conventional rolling and the new rolling method

Table 4 Effect of reducing the number of guide facilities

	Edging roll	
	Conventional	New
Kind of shape	23	1
Number of rolls	30 set	1 set

4 Conclusions

To economically manufacture H-beams with fixed outer demensions by the hot rolling process, tests were conducted via model experiments and established the techniques for controlling the outer dimensions of H-beams. The results obtained are as follows:

(1) An inner web width reduction method using a universal rolling mill was developed to control the web depth.
(2) With this rolling method, the flange thickness can be reduced at the same time as the reduction of the inner web width to prevent shape defects and give high dimensional accuracy.
(3) A flange width reduction method using grooveless edger rolls was developed to control the flange width.
(4) This method utilizes flange end guiding on a universal rolling mill to improve the web off-centering accuracy, which is necessary to accurately control the flange width.
(5) The combination of these two rolling methods enables size-free rolling of H-shapes to be achieved, and can easily be applllied to existing equipment.

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