KAWASAKI STEEL TECHNICAL REPORT
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# A New Rolling Method of Slab into Beam Blanks for Large H-shapes*

Tadaaki YANAZAWA** Teruaki TANAKA** Masashi YAMASHITA**
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*The effects of the new method are as follows:*

*(a) Improvement in yield (product/crude steel): 12%*
*(b) Energy saving: 150 × 10³ kcal/t*
*(c) Improvement in H-shape quality; Few surface and internal defects*

## 1 Introduction

Dimensions of H-shapes are classified into 33 series in JIS and 44 series in ASTM, totaling as many as 77 series. In order to rationalize manufacturing steps in rolling these H-shapes, it is meaningful to develop economical material producing techniques.

Blooms and beam blanks are used to produce H-shapes. It is usual practice to use blooms for the "junior size" in which the sum of the web height and flange width is 450 mm or less, and to use beam blanks for the "senior size" in which the sum of the web height and flange width exceeds 450 mm. The sectional shapes of beam blanks are designed based on the required dimensions of H-shapes, and it is considered necessary to use exclusive beam blanks that correspond to the respective H-shape series. In recent years, transition in production process from the conventional ingot-making and blooming to continuous casting has been under way in many types of products, in order to improve yield and internal and surface quality and to achieve cost saving by energy-saving operation. Also in producing H-shapes, the "junior size" series have already been continuously cast by using widely-adopted bloom CC machines, whereas continuous casting of the "senior size" series was dragging slowly because it required a large number of beam blank molds, thereby sharply raising the cost of initial investment and bringing a notable drop in productivity of CC machines due to frequent changes in molds. Kawasaki Steel Corporation made an enthusiastic introduction of continuous casting process by rolling continuously-cast beam blanks of a single size into H-shapes[1] measuring H600 × 300 and H350 × 350 (web height × flange width in mm), as a result of developing rolling techniques for producing multiple-series H-shapes from a single-size beam blank. The only remaining task was to produce large H-shapes exceeding the limits of application of the beam blank in continuous casting process. Recently the use of continuous casting for all series of H-shapes has been successfully accomplished as shown in **Fig. 1** with the development of new beam blank rolling techniques for rolling CC slabs into H-shapes (hereafter called "slab method"). The basic techniques of the slab method comprise the following two:

(1) Width rolling (edging) of slab
(2) Partial web rolling

The development of the slab method has brought

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** Mizushima Works

*** Research Laboratories

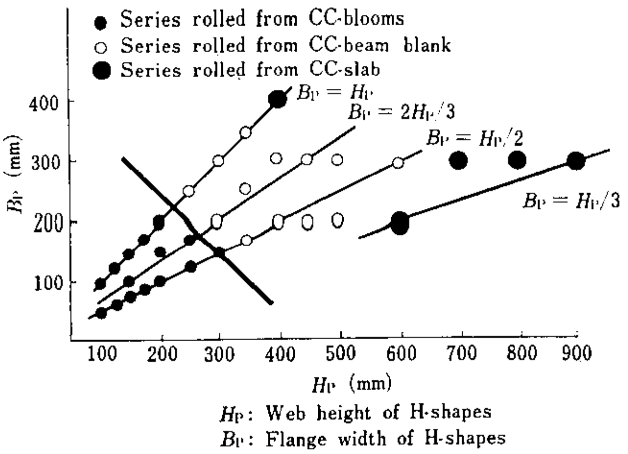


**Fig. 1** Relation between dimensions of H-shapes and applied materials

about great results such as improvement in yield, decrease in excess product ratio and surface defect, and energy saving. Circumstances involved in developing the slab method and the detail are described below.

## 2 Conventional H-shape Rolling Techniques

Previously large H-shapes were manufactured from beam blanks which were formed by the pass rolling of steel ingots by way of formed initial sections as shown in **Fig. 2**. In this method, a large web tongue is formed as shown in **Fig. 3** during rolling the initial section into the beam blank, thereby greatly lowering the yield. Also shrinkage holes and concentrated segregation portions at the head of the ingot have to be cut off as crops, thereby not only lowering the yield but also widening the variation of the yield itself at normal times. Further difficult problems are posed by generation of surface defects represented by seams and scabs on semi-killed steel. These surface defects are difficult to prevent completely, resulting in an increase in the pretreating load of beam blanks and often in the massive generation of defective products.

As a result of such variation in yield and quality instability as mentioned above, various difficult problems occurred such as lowering the achieving ratio of the plan for proper matching of products with materials, frequent occurrences of superfluous products and disturbance of production steps. On the other hand, sectional dimensions of beam blanks were designed by tracing back the rolling step shown in **Fig. 2**, and consequently, provision of exclusive beam blanks was essential for almost all product series, thereby obstructing process rationalization by means of integration and consolidation of material shapes.

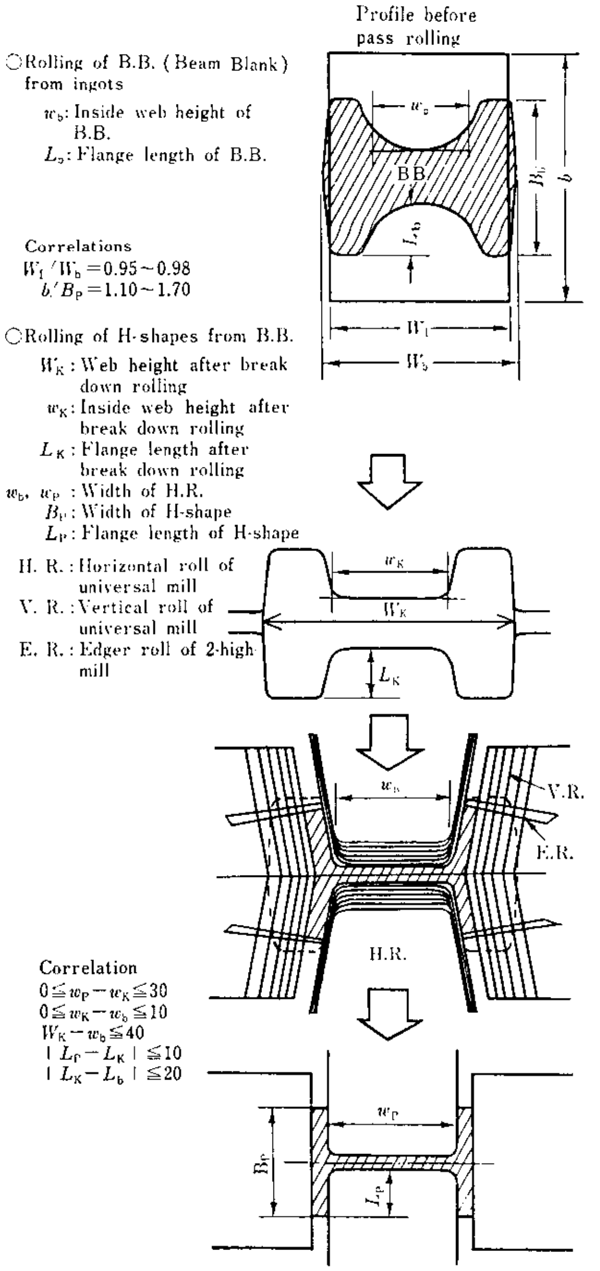


**Fig. 2** Conventional rolling process for H-shapes from ingots

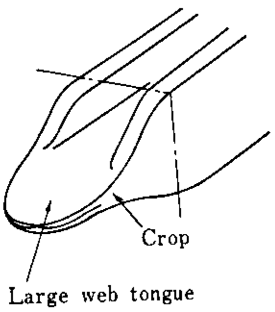


**Fig. 3** Formation of crop after rolling of B. B. from an ingot

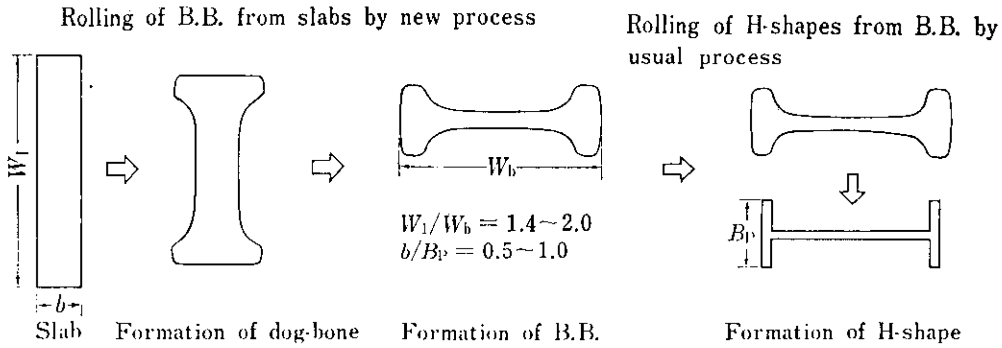


**Fig. 4** New rolling method of B. B. from slabs

## 3 Rolling H-shapes from Slabs

When a slab is edged, the rolling reduction strain does not penetrate into the slab center, but is concentrated on both edges alone, resulting in width spread and a double bulging shape, as is well known. The idea that "if edging is further continued, the dog-bone shape will be formed" is the starting point of developing the slab method. On the basis of this idea and with the two pillars of development, i.e., the edging techniques employing the belly method, and the partial web rolling techniques to be explained later, it has become possible, simply by the progress in rolling techniques, to put to practical use the method of rolling the slab into a large H-shape. The outline of the slab method is shown in **Fig. 4**. This method features the spreading generated at both edges of the slab by heavy reduction in the web height direction, thereby forming flanges wider than the slab thickness, contrary to the ingot method shown in **Fig. 2**, in which flanges are formed by heavy reduction in the web width direction. In the slab method, the key point in rolling is how to obtain the largest sectional area of each flange.

### 3.1 Wide Adoption of CC Due to Development of Belly Method

The fundamental point of the slab method is the formation of flanges of the beam blank by edging. What is required of the beam blank is that it is free of nonuniform dimensions which will be directly connected to defects in the size and shape of products in the succeeding universal rolling step. Particularly in slab edging, it is more difficult than in the ingot method to maintain uniform shapes of flanges, because flange forming by free spread formation is employed in the former rolling method. Thus the success in obtaining uniform flange shapes is the key point of the slab method. As shown in **Fig. 5**, the slab is liable to collapse during edging by giving load of an unstable form to the flat shape, immediately resulting in nonuniform flange shapes. Once this collapsing trend occurs, it is impossible to correct it in the course of rolling operation. Therefore, a great task required in developing the slab method is how to add heavy edge reduction, while avoiding the slab collapsing in rolling operation.

#### 3.1.1 Belly method

One of the methods of preventing the slab collapsing during edging is to use box passes having a larger width in sequence, but the practical use of this method is difficult, because it requires a large number of passes, and yet it cannot completely prevent the slab collapsing. Rolling of a dog-bone by the belly-pass method is a method recently conceived with the

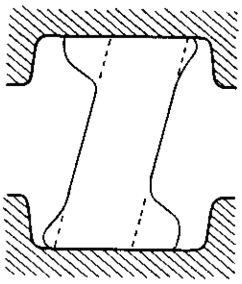


**Fig. 5** Inhomogeneous deformation of a slab at edging

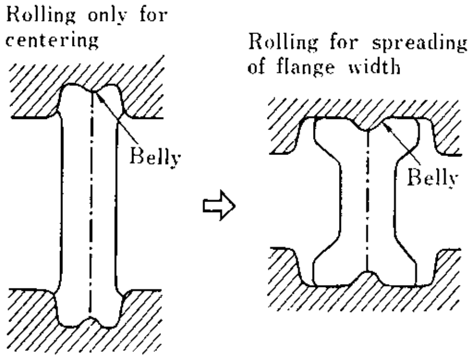


**Fig. 6** New rolling method by passes with belly for homogeneous formation of flanges at edging

**Table 1** Summary of the application of new B. B. rolling method from slabs for large H-shapes

| Dimensions of H-shapes $H_P \times B_P$(mm) ($H_P$ : Web height, $B_P$ : Flange width) | Dimensions of slab $W_1 \times b$ (mm) ($W_1$ : slab width, $b$ : slab thickness) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | After development of the new edging method | | | | After development of partial web rolling method | | | |
| | via B.M. | without B.M. | $B_P/b$ | $W_1/H_P$ | via B.M. | without B.M. | $B_P/b$ | $W_1/H_P$ |
| 400×400 | — | 1 100×250 | 1.6 | 2.8 | — | 1 100×250 | 1.6 | 2.8 |
| 600×200 | — | 1 100×250 | 0.8 | 1.8 | — | 1 100×250 | 0.8 | 1.8 |
| 700×300 | 1 500×215 | — | 1.4 | 2.1 | — | 1 225×250 | 1.2 | 1.8 |
| 800×300 | 1 650×240 | — | 1.3 | 2.1 | — | 1 400×250 | 1.2 | 1.8 |
| 900×300 | 1 650×240 | — | 1.3 | 1.9 | — | 1 400×250 | 1.2 | 1.6 |

B.M. : Blooming mill

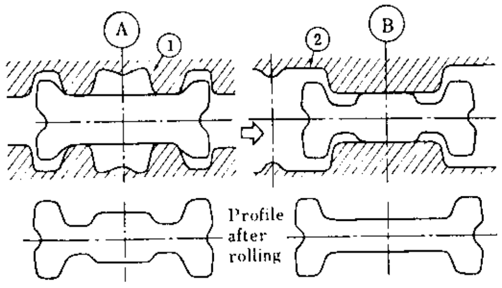
objective of performing stabilized edging with a minimum number of passes. In the belly-pass method, a protrusion called the "belly" is provided at two points, one at top and the other at bottom, on the central axis of the pass as shown in **Fig. 6**. This belly correctly guides the slab to the center of the pass and also functions to prevent the slab from collapsing, thereby effectively contributing to a stable edging operation.

### 3.1.2 Application of belly method

The slab method was put to practical use by applying the belly method to the blooming mill and the break down mill (hereafter called "B.D.M.") at the Wide Flange Beam Mill. Particulars obtained from the application are shown in **Table 1**. As is shown by $B_P/b$ in the **Table 1**, H-shapes were successfully rolled to have a flange width ($B_P$) 1.6 times the original slab thickness ($b$). At first, H-shapes of H400 × 400 and H600 × 200 only were rolled directly from slab at the wide flange beam mill (1-heat rolling), and other H-shapes were rolled on the blooming mill (2-heat rolling).

## 3.2 One-heat Rolling by Partial Web Rolling Method

As shown in **Table 1**, the slab width applied to H-shapes H700 × 300, H800 × 300, and H900 × 300 was 1 500 to 1 700 mm. For H-shapes of these sizes, it was impossible to apply the 1-heat rolling because the slab width exceeded the maximum opening (1 400 mm) between the upper and lower rolls of the B.D.M. at the Wide Flange Beam Mill and it was also impossible to accommodate the required pass inside the roll barrel length (2 800 mm) of the B.D.M. Therefore, a new partial web rolling method (hereafter called the "partial web method") was conceived to eliminate the above restrictions, thereby achieving 1-heat rolling of all series of large H-shapes from CC slabs, by passing the slabbing mill.



Partial web rolling (both ends) and formation of flanges

Partial web rolling (middle section) for spreading of web height

**Fig. 7** Partial web rolling method to form flanges of B. B. effectively

### 3.2.1 Partial web method

The concept of the partial web method is to get various advantages mentioned below by repeating two types of rolling Ⓐ and Ⓑ at the time of web reduction as shown in **Fig. 7**.

(1) Flanges are formed from a narrower slab: Namely, in rolling Ⓐ and Ⓑ, deformation in the rolling direction is constrained with the non-reduced portion, so that elongation will be minimized and the decrease in the flange area will be suppressed. Since spreading deformation inevitably becomes larger and the inside width of the web is enlarged, the quantity of edging can be secured. As a result, the flange formation becomes possible in the same degree as in the case of a wider slab.

(2) Necessary passes can be accommodated in the limited barrel length of the B.B. rolls: This can be made possible by using passes ① and ② shown in **Fig. 7** for the purpose of edging.

(3) B.D. rolling load can be reduced: Since the B.D. rolling is partial rolling and the flange part is subjected to non-constraint rolling, the rolling load can be reduced.

### 3.2.2 Application of partial web method

As a result of practical use of the partial web method, it has now become possible to manufacture all sizes of large H-shapes at 1 heat. Particulars of this manufacture are shown in **Table 1**. Namely, it has become possible to roll H-shapes H700 × 300, H300 × 300, and H900 × 300 from a slab 250 to 300 mm narrower in width than the conventional slab which was rolled on the blooming mill.

## 4 Pass Scheduling of Slab Method

The pass scheduling of beam blanks by the slab method based on the belly-pass method and the partial web method is explained in more detail below.

### 4.1 Pass Scheduling of Belly Method

The method of rolling beam blanks by the belly method consists of the following 4 steps as shown in **Fig. 8 (a)**:

(1) Slab centering rolling
Caliber ① having its width approximately equal to the slab width is used for cutting the belly groove at the center of both sides of slab.

(2) Flange spreading rolling
In the pass ② operation, the blank is edged through multiple passes under light reduction, while being constantly guided to the pass center with the help of the belly groove, thereby spreading the flange width actively. At this time the blank is not constrained by the side walls of the pass, but is guided only by the belly.

(3) Belly groove erasing rolling
Pass ③ having the normal flat bottom is used for final edging to erase belly grooves.

(4) Beam blank forming rolling
The dog-bone, which has been obtained by edging of the slab at heavy reduction, is turned over, and a beam blank is formed by pass ④.

As a characteristic of this belly method, crop shapes at the top and bottom ends give smaller web tongues than by the ingot method. It may be said, therefore, that the slab method has a higher yield than the conventional ingot method.

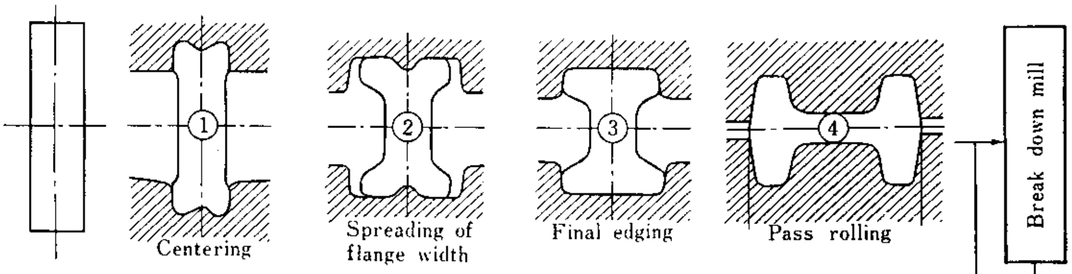
### 4.2 Pass Scheduling of Partial Web Method

The partial web method consists of the following 6 steps as shown in **Fig. 8 (b)**:

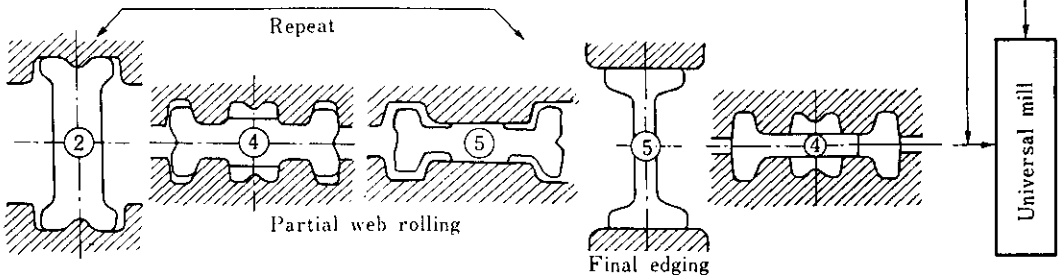
(1) Slab centering rolling by pass ①

(2) Flange spreading rolling by pass ②
The above two steps are the same as those in the belly method mentioned above.

(3) Partial web rolling
This is the most important step in this method. First, pass ④ is used for simultaneously forming the flanges and reducing both ends of the web (near the roots of flanges). At this time the web center is not reduced but takes a convex shape. Next, pass ⑤ is used to reduce only the convex portion of the web to spread its inside width.



(a) Developed rolling method of H-shapes from slabs including new edging method by pass with belly



(b) More advanced rolling method of H-shapes from slabs including partial web rolling method

**Fig. 8** Developed new rolling method of B. B. from slabs

Since the non-reduced portion constrains elongation in the rolling direction at this time, deformation due to reduction is centered on width spreading. At this time, however, flanges must be kept free.

(4) Flange spreading rolling
Pass ② is again used to edging the expansion allowance of the web inside width obtained by step (3) above, in order to increase each flange area. The unique rolling step of this method is to repeat the above steps (3) and (4) several times to complete formation of flanges each having a necessary sectional area.

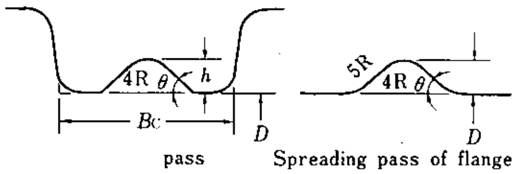
(5) Belly groove erasing rolling
Pass ⑤ is used for rolling to erase the belly grooves.

(6) Beam blank forming rolling
Finally pass ④ is used to finish a beam blank suitable for universal rolling.

In rolling by pass ⑤ at step (3) in the partial web method, adjustment of the ratio of the width × thickness of the convex portion to the entire cross-sectional area will minimize elongation in the rolling direction and yet expand the web inside width that corresponds to the area decreased by rolling.

## 5 Deformation Characteristics during Rolling by Slab Method

Prior to practical application of the slab method, an investigation was made on the deformation behavior during rolling by using a plasticine model mill in order to establish detailed manufacturing conditions of H-shapes. As a result of this investigation it was possible to obtain deformation characteristics which will be useful background information in determining the detailed dimensions of passes to be used in actual mill rolling as well as slab dimensions.



| Pass No. | θ (°) | h (mm) |
|---|---|---|
| No. 1 | 30 | 5 |
| No. 2 | 45 | 3 |
| No. 3 |  | 5 |
| No. 4 | 60 | 7 |
| No. 5 |  | 5 |

$D$ : Roll diameter ($D$=270 mm)
$Bc$ : Width of centering pass
(Just the same as width of each specimen)

**Fig. 9** Profile of rolls with belly for edging experiment of plasticine models (scale: 1/10). For comparison, a flat roll without belly was also used.

### 5.1 Deformation Characteristics during Edging

An investigation was conducted mainly aimed at the width-spreading behavior during edging and changes in the length of the non-stationary deformation range during rolling at the top and bottom ends. Symbols used below are defined as follows:

$D$: Roll diameter
$B_0$: Slab width (before rolling)
$B_{1\max}$: Max. slab width (after rolling)
$H_0$: Slab thickness (before rolling)
$H_1$: Slab thickness (after rolling)
$B_0/H_0$: Slab width ratio
$D/H_0$: Slab thickness ratio
$(H_0 - H_1)/H_0$: Total draft
$B_{1\max}/B_0$: Max. spread ratio
$\lambda$: Elongation raio

#### 5.1.1 Experimental method

Two types of rolls (belly roll and flat roll), with belly and the latter without belly for comparison, were used; the scale for the material made of plasticine was 1/10. For the roll with belly, 5 shapes with different heights ($h$) and root angles ($\theta$) as shown in **Fig. 9** were used, and the width of the centering pass ($B_C$) was always made the same as that of the slab. For the pass schedule, the first rolling was made through the centering pass and then edgings were performed through the spreading passes of the same belly shape. After each rolling, measurement was made on changes in the gauge interval of the material surface and also on changes in various measurements as shown in **Fig. 10** in the stationary deformation range. Prior to the experiment, a comparison of deformation state was made between the actual mill and its plasticine model, thereby confirming that simulation by model rolling was feasible.

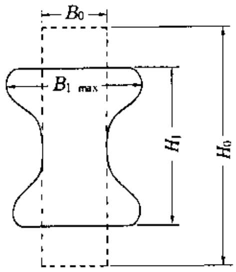


**Fig. 10** Shape after edging of plasticine models (scale: 1/10)

### 5.1.2 Deformation characteristics of stationary range during edging

Investigation was made on rolling reduction per pass, slab width ratio, and the belly shape as factors that would affect the deformation states of slabs, as follows:

(1) Effects of rolling reduction per pass and $B_0/H_0$
**Fig. 11** shows the effect of rolling reduction per pass on the spread ratio when a flat roll is used. From this figure, it is observed that the smaller the rolling reduction per pass, the larger the spread ratio and that as the total rolling reduction increases, the difference becomes more conspicuous. **Fig. 12** shows the tendency of spread ratio changes under the total reduction with the same parameters of $D/H_0$ (2.45) and reduction (4 mm/pass). From this figure, it is observed that the smaller the parameter $B_0/H_0$, the spread ratio becomes larger under the same reduction, and the difference becomes more conspicuous, as reduction progresses.

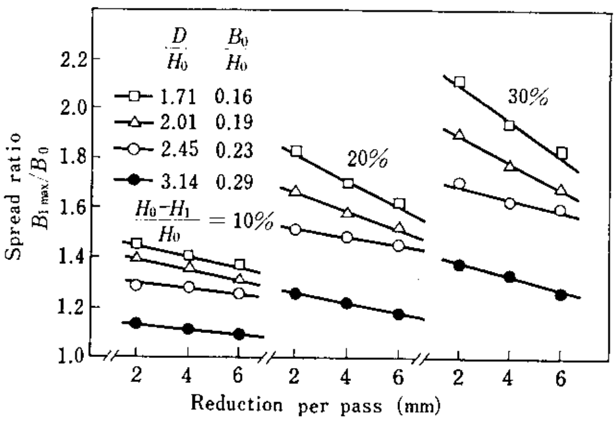


**Fig. 11** Relation between spread ratio and reduction per pass during edging by a flat roll

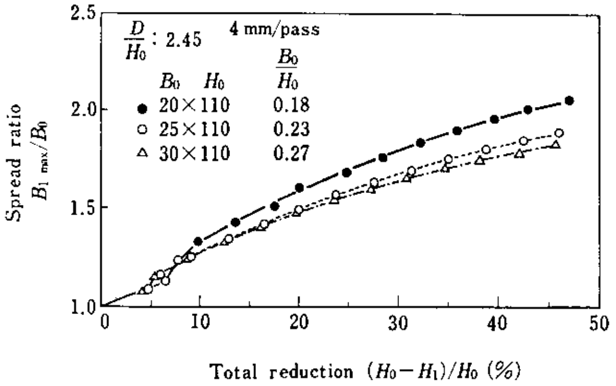


**Fig. 12** Relation between spread ratio and total reduction under the same $D/H_0$ (2.45), reduction (4 mm/pass) and belly ($\theta$ = 45°, $h$ = 5 mm)

(2) Difference between roll with belly and flat roll
**Fig. 13** shows a comparison between rolls with and without belly concerning the effects of parameters such as $B_0/H_0$, $D/H_0$, and draft upon the spread ratio. This figure indicates that edging with belly gives a spread ratio about 10% larger than that in edging without belly. It can be said, therefore, that the roll with belly is better for flange forming.

(3) Effects of belly shape
**Figs. 14** and **15** show the influence of the belly shape ($\theta$ and $h$) on the spread ratio. They indicate that the smaller the belly angle ($\theta$) and the greater the belly height, the larger is the spread ratio.

(4) Distribution of tensile strain in width direction
**Fig. 16** shows the distribution of tensile strain (spread ratio) in the width direction at various positions in the cross section, when two plasticine models of 5 mm each in thickness having $H_0 \times B_0 = 110 \times 30$ mm are stuck together in the width direction at a rolled posture and rolled at a reduction of 4 mm/pass into a thickness of 62 mm. The abscissa and ordinate indicate strain in the width direction and positions in the thickness direction, respectively. A belly roll of $\theta$ = 45°, $h$ = 5 mm was used. From **Fig. 16**, it is observed that there is no great difference in strain distribution at the ends in the width direction ($B_x/B_0$ = 0.92) between the roll with belly and the flat

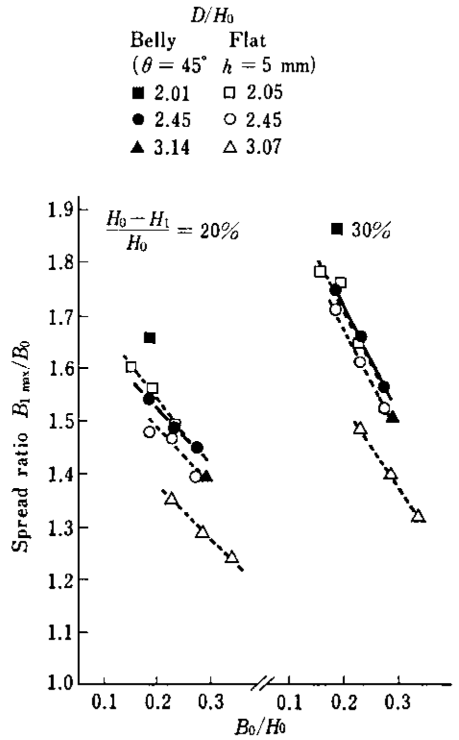


**Fig. 13** Comparison of spread ratio after rolling between rolls with and without belly

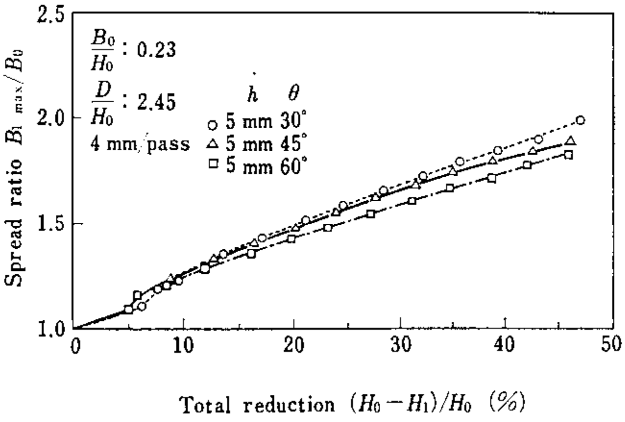


**Fig. 14** Influence of $\theta$ on spread ratio after rolling under the same $B_0/H_0$ (0.23), $D/H_0$ (2.45) and reduction (4 mm/pass)

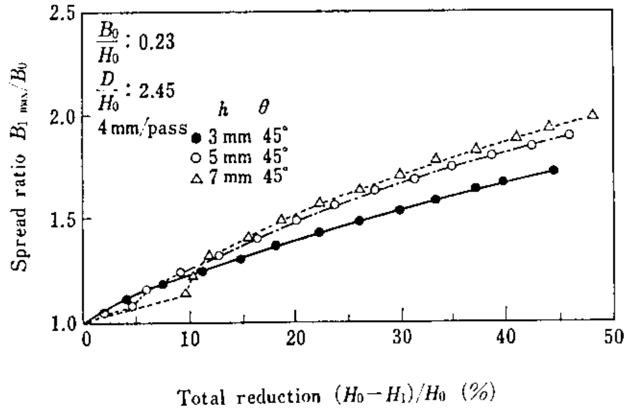
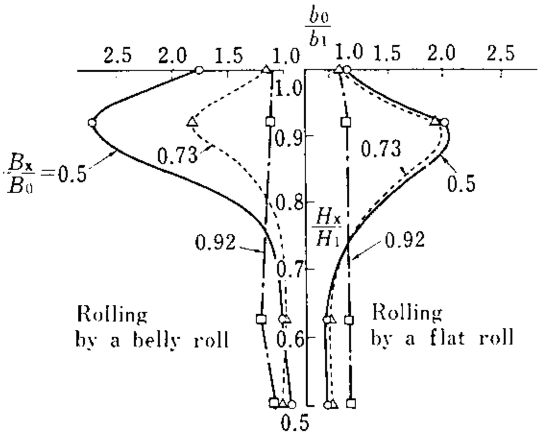


**Fig. 15** Influence of $h$ on spread ratio after rolling under the same $B_0/H_0$ (0.23); $D/H_0$ (2.45) and reduction (4 mm/pass)



$B_x$ : Distance from surface along the through-width direction before rolling

$b_0$, $b_1$ : Width of small element at $B_x$ before and after rolling ($b_0=5$ mm)

$H_x$ : Distance from surface along the through-thickness direction after rolling

$H_1$ : Thickness after rolling

**Fig. 16** Distribution of $b_1/b_0$ along the through-width direction after edging of a plasticine model ($B_0 \times H_0 = 30 \times 110$ mm) under the same reduction (4 mm/pass)

(no-belly) roll, but the difference becomes larger near the reduction surface at the center in the width direction ($B_x/B_0 = 0.5$), and strain for the belly roll is larger. Upon investigation of the material incompletely rolled, it was found that the difference was caused by the different deformation states of the slab when the roll came into contact with the reduction surface of the material. Namely, flat roll comes into contact simultaneously over the entire width of the reduction surface of the material, and rolling reduction force is applied in the vertical direction, so that the contact surface is deformed while being firmly fixed to the roll surface, whereas for the roll with belly, the contact of the roll with the material first begins at the belly portion. Then before the roll comes into contact with flat portions on the right and left, a great spread occurs and the metal is rolled by being pushed apart to the right and left by the convex belly. With these two effects, rolling by the belly roll gives a larger spread ratio.

### 5.1.3 Length of non-stationary deformation range

Upon investigation on the crop length at the top and bottom ends of the slab which governs the magnitude of the yield, it was found that the crop length was greatly dependent upon $H_0/D$, and the following empirical formulas have been obtained regarding the length of the non-stationary range.

For flat roll:

$$C_{\mathrm{flat}} = \{100 + 153(H_0 - H_1)/H_0\}H_0/D \quad \cdots\cdots\cdots\cdots\text{(1)}$$

For roll with belly:

$$C_{\mathrm{belly}} = \{85 + 119(H_0 - H_1)/H_0\}H_0/D \quad \cdots\cdots\cdots\cdots\text{(2)}$$

Therefore, it is observed that the length of the non-stationary deformation range is determined by $H_0/D$ and the draft; and the smaller the $H_0$ and the smaller the draft, the length of the non-stationary deformation range becomes shorter. It is also found that the roll with a belly is advantageous for reducing the length of the non-stationary deformation range.

### 5.1.4 Collapse of material during edging

Upon observation on collapse of the material during the experiment, the following was observed:

(1) The belly is effective in prevention of collapse, but if the (belly width)/(material thickness) becomes larger, twisting is liable.
(2) Collapse is not caused by the buckling of the raw material, but by its twisting.

### 5.1.5 Application of experimental results to actual mill

The above-mentioned experimental results were confirmed by the actual mill, and actual operation is going on. An example of operating conditions for such actual operation is given below.

(1) Belly shape
The angle and height of the belly are 40° to 45° and 40 to 45 mm, respectively.
(2) Reduction per pass
The reduction per pass is set to 30 to 40 mm, with the overall consideration of the number of passes, spread ratio and stable rolling operation.
(3) Determination of slab dimensions
Slab dimensions are determined by using the following equations **(3)** and **(4)**, so that the sizes determined will match the facility conditions of Kawasaki, and under overall consideration of heating furnace efficiency and rolling efficiency:

$$K(W_1 - W_2) \geqq B_b + a(b - t) - b \quad \cdots\text{(3)}$$

$$h(W_1 - W_2) \geqq 4(1 + \alpha)S \quad \cdots\cdots\cdots\cdots\text{(4)}$$

$K$: The spread ratio by edging
$a$: The decreasing ratio of flange width when it is rolled to a web thickness of $t$
$\alpha$: Spread efficiency, i.e., a correction factor of flange metal decreasing

For other symbols used in the above equations, refer to **Fig. 17**.

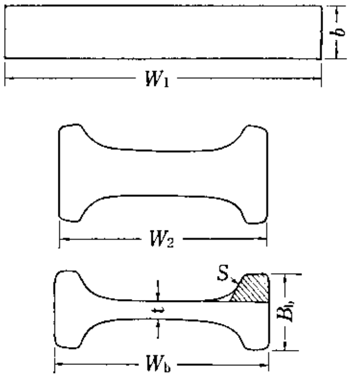


**Fig. 17** Definitions of cross sections of material applied to equations (3) and (4)

## 5.2 Deformation Characteristics during Partial Web Rolling

Deformation behavior of a slab during reduction of the convex part of the web, which is one of the most important processes in the partial web rolling method, was clarified, thereby making it possible to predict the shape of the material after rolling.

### 5.2.1 Model equations in rolling convex part of web

By application of the metal flow formula for rolling the web of a dog-bone material independently the following equations have been derived as shape prediction formulas when the convex part of the web is rolled from $T_0$ to $T_1$ as shown in **Fig. 18**:

$$\lambda = T_0 \cdot B_r/(\Delta M + T_1 \cdot B_r) \quad \cdots\cdots\cdots\cdots\text{(5)}$$

$$S_1 = S_0/\lambda \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\text{(6)}$$

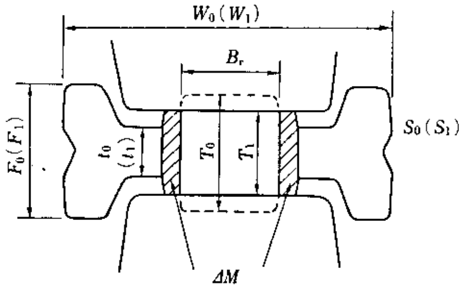
$$W_1 = B_r + (W_0 - B_r)/\sqrt{\lambda} + \Delta M/T_1 \quad \text{(7)}$$

$$F_1 = F_0/\{1 + 0.73(\sqrt{\lambda} - 1)\} \quad \cdots\cdots\text{(8)}$$

$B_r$: Width of direct reduction part
$S_0$, $S_1$: Sectional areas of material before and after rolling
$W_1$: Height of web after rolling
$F_0$, $F_1$: Flange widths before and after rolling
$\Delta M$: Amount of metal flowing out from the direct reduction part. $\Delta M$ has the following relation[2]:

$$\Delta M = \Delta M_1 + \Delta M_2$$
$$\begin{cases} \Delta M_1 = f(T_0, T_1, B_r, D) \\ \Delta M_2 = f(S_{F0}/S_0, T_0, T_1, B_r, D) \\ S_{F0} = S_0 - T_0 B_r \end{cases}$$

$\Delta M_2$ is a metal flow generated because non-reduction portion (area: $S_{F0}$) exists, and becomes greater, as the ratio of non-reduction portion to the total area ($S_{F0}/S_0$) becomes larger. $\Delta M_1$ is a metal flow generated when it is assumed that portion $B_r$ is plate rolled.



$\Delta M$ : Amount of metal flow after rolling
$S_1$, $S_0$ : Sectional area
$S_{F0} = (S_0 - T_0) \times B_r$

**Fig. 18** Dog-bone profile at partial web rolling (Suffix 0 and 1 show before and after rolling)

### 5.2.2 Deformation characteristics during partial web rolling

An examination was made on factors that would affect changes in shapes during partial web rolling by using the shape prediction formula, as a reference for setting up rolling conditions.

(1) Effect of direct reduction portion width ($B_r$)
**Fig. 19** shows elongation coefficient ($\lambda$) during partial web rolling. The figure indicates an example when the convex portion width ($B_r$) is reduced at 3 levels by making constant the initial sectional area of material having the shape shown in **Fig. 18.** The pass schedule shown in **Table 2** was used and, for simplicity, calculation was made by assuming that no changes in elongation would occur in web end rolling and edging. **Fig. 19** indicates that as $B_r$ becomes smaller, $\lambda$ also becomes smaller, and as the web thickness is reduced, the variation quantity of $\lambda$ also is reduced. **Fig. 20** shows changes in the flange width, indicating that as $B_r$ becomes smaller, the width of the flange with reduced thickness increases. The key point in partial web rolling is to reduce rolling elongation and prevent decrease in the flange area, and thus it is found advantageous to reduce $B_r$ within the practical range.

**Table 2** Pass schedule of partial web rolling

| Pass No. | $T_1$ | $t_1$ | $W_1$ | Notes |
|---|---|---|---|---|
| 0 | $T_0$ | 180 | 931 | Edging rolling (E.R.) |
| 1 | 180 | — | — | Partial web rolling (P.W.R.) |
| 2 | — | — | 931 | E.R. |
| 3 | — | 150 | — | P.W.R. |
| 4 | 150 | — | — | |
| 5 | — | — | 931 | E.R. |
| 6 | — | 120 | — | P.W.R. |
| 7 | 120 | — | — | |
| 8 | — | — | 931 | E.R. |
| 9 | — | 105 | — | P.W.R. |
| 10 | 105 | — | — | |
| 11 | — | — | 931 | E.R. |
| 12 | — | 90 | — | P.W.R. |
| 13 | 90 | — | — | |
| 14 | — | — | 931 | E.R. |
| 15 | — | 65 | — | P.W.R. |
| 16 | 65 | — | — | |

$T_1$, $t_1$, $W_1$, and $T_0$ are shown in Fig. 18

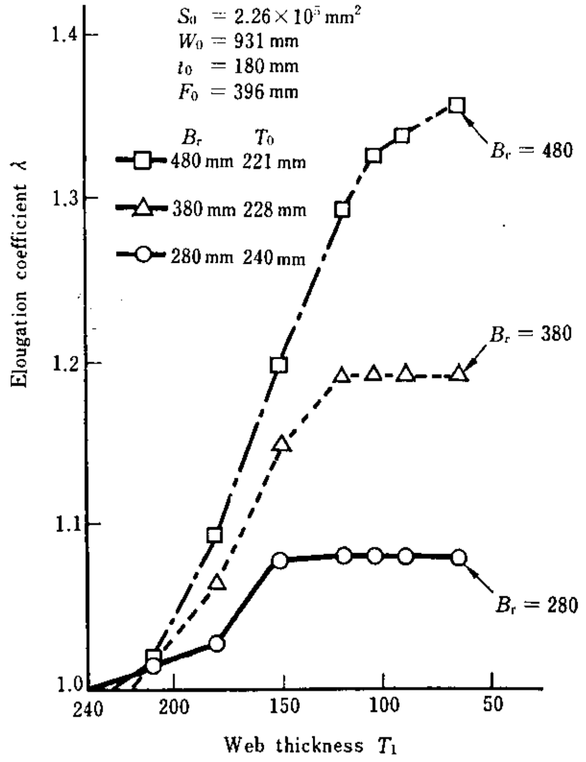
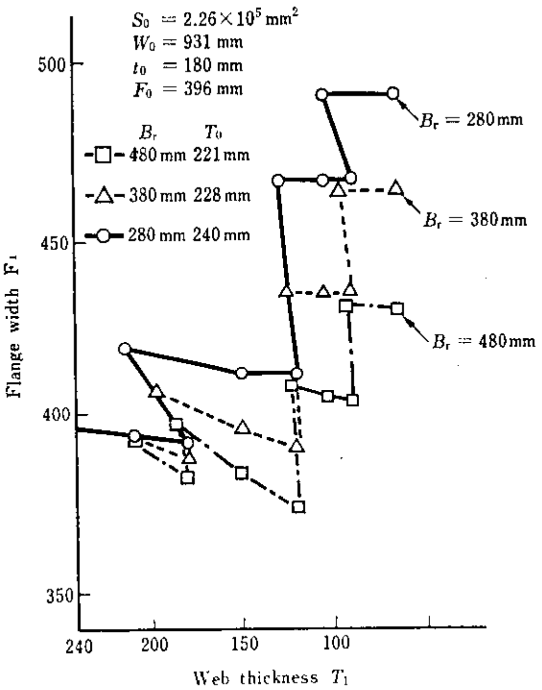
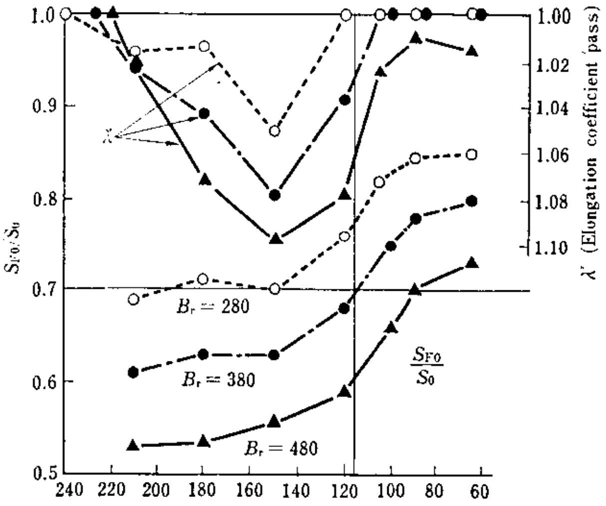


**Fig. 19** Effect of $B_r$ on elongation coefficient under partial web rolling by using pass schedule shown in Table 2



Rolling conditions are the same as Fig. 19

**Fig. 20** Effect of $B_r$ on flange width on the assumption of $\lambda = 1$ at edging and partial web rolling (both ends)



Rolling conditions are the same as Fig. 19

**Fig. 21** Change of $S_{F0}/S_0$ and elongation coefficient per each pass caused by the decrease of web thickness

(2) Effects of non-reduction portion area ($S_{F0}/S_0$)
**Fig. 21** shows changes in $S_{F0}/S_0$ and elongation coefficient ($\lambda'$) per pass under the same rolling conditions as in **Fig. 19**. **Fig. 21** indicates that as the web thickness decreases, $S_{F0}/S_0$ gradually increases until $\lambda' \fallingdotseq 1$ is obtained in the area of $S_{F0}/S_0 > 0.7$, exhibiting practically no elongation. The convergence of $\lambda$ in **Fig. 19** is attributable to the increase in $S_{F0}/S_0$. From this fact, it can be said that what is important in partial web rolling is to create the conditions as early as possible under which $S_{F0}/S_0 > 0.7$ is obtained.

The reason why the behavior during partial web rolling is changed by $B_r$ is attributed to the fact that $B_r$ changes $S_{F0}/S_0$, thereby indicating that establishment of the value of $B_r$ is very important.

### 5.2.3 Rolling elongation during forming by each pass

When the slab was formed into the dog-bone shape ready for universal rolling, the ratio of elongation by each pass to the total elongation was as shown in **Table 3**. This ratio is an example for H900 × 300 rolled by the actual mill, but the elongation ratio to the total elongation in edging is small and the ratio in convex portion rolling is 27%. The elongation coefficient in the rolling for reducing web ends shows a large value, but a certain degree of elongation is considered inevitable, because this rolling is playing the role of forming the flange shape. Therefore, it is important to minimize elongation during reduction of the convex portion.

**Table 3** An example of elongation coefficient ($\lambda_T$) at each rolling

| | Slab | Partial web rolling | | Edging | Finish of B.D.M. |
|---|---|---|---|---|---|
| | | (both ends) | (middle section) | | |
| Area of section (mm$^2$) | 215×1 400 =301 000 | — | — | — | 142 244 |
| λ | 1.0 | 1.718 | 1.304 | 1.094 | 2.116 |
| $\lambda_T$ | — | 64% | 27% | 9 % | 100% |

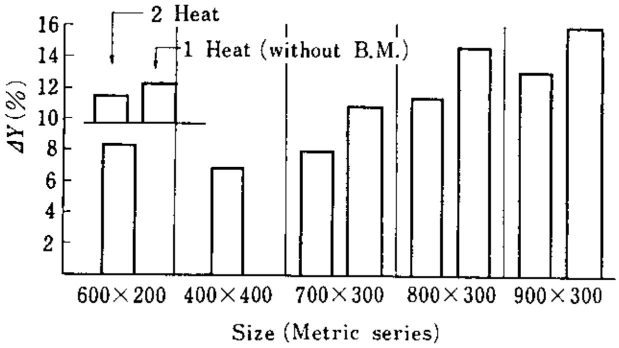
$\lambda_r = 2.116$: Elongation coefficient from slab to final shape at B.D.M.

## 6 Effects Obtained by Slab Method

With the development of the slab method, it has become possible to produce large H-shapes whose dimensions satisfy requirements by JIS and ASTM from CC-material and to manufacture them by 1-heat rolling. As a result, an outstanding outcome as shown below has been obtained.

(1) Remarkable improvement of yield
  (a) The new beam blank rolling method itself minimizes the crop loss and gives a high yield as mentioned earlier.
  (b) Omission of material pretreatment as a result of obtaining CC material of high quality.
  (c) Reduction in product defects owing to unsatisfactory material.
  (d) Reduction in cutting off good quality portions with the help of improvement on accuracy of materials weight.

With the above-mentioned improvements, the overall yield of crude steel vs. products has improved to 7 to 16% according to product sizes and 12% on the average as shown in **Fig. 22.**



$\Delta Y = Y_{slab} - Y_{ingot}$
$Y_{slab}$ : Yield by new process
$Y_{ingot}$ : Yield by conventional process
Yield : Products/Crude steel

**Fig. 22** Yield improvement by new B. B. rolling method

(2) Enhancement of prime product obtainable ratio
As a result of improvement on accuracy of materials weight and reduction in defective products caused by defective materials, the achieving ratio of the plan for proper matching of products with materials has been enhanced and the overproduction generation ratio has been markedly reduced from 7% to 1.5%.

(3) Energy saving
As a result of 1-heat rolling by omitting the blooming step, an energy saving of about $150 \times 10^3$ kcal per product ton has been achieved.

(4) Improvement in product quality
Since rolling from semi-killed steel ingot has been dispensed with, it has become possible to manufacture large H-shapes of high quality free of seams and internal defects.

(5) Rationalization of manufacturing steps by integration and consolidation of materials
With improved interchangeability of materials between various sizes of H-shapes and common use of materials for H-shapes and plates, production of special order products and small order products has become economical.

(6) Facility investment lowering effect
Feature of the slab method lies in the modification of rolls alone, not requiring any new facility investment. In the past, manufacturing of large H-shapes from CC material required installation of a large scale beam blank CC machine, but the slab method has made such a machine unnecessary.

## 7 Conclusion

With the development of the slab method based on the belly method and the partial web method, a new step for rolling slabs into H-shapes by 1-heat rolling has been established. Consequently, it has become possible to manufacture from CC steel all sizes of H-shape satisfying JIS and ASTM specifications, thereby greatly rationalizing of materials manufacturing steps, with quality improvement and cost saving. The trend toward continuous casting process will become common to all types of products in the future, and what function is to be given to CC shop and rolling shop will remain a future task. Improvement in material processing techniques in the rolling shop, as exemplified by rolling H-shapes in the slab method, is effective in positioning the CC shop as a mass production and high productivity manufacturing step. Manufacture of H-shapes by the slab method will expand in the future as techniques suitable to steelworks equipped with slab CC machines in producing H-shapes in comparatively smaller quantities with many sizes.

### References

1) T. Tanaka et al.: *Kawasaki Steel Technical Report*, **10** (1979) 4, pp. 69–78 (in Japanese)
2) T. Kusaba et al.: *Kawasaki Steel Giho*, **13** (1981) 3, pp. 13–25