Rolling of T-Shaped Profiled Strip by the Satellite Mill

H. Utsunomiya, Y. Saito, T. Hayashi, and T. Sakai

A new type of compact mill called a "satellite mill" is used for producing T-shaped profiled strip from flat strip. The mill comprises one large-diameter flat roll (central roll) and five smaller-diameter caliber rolls (satellite rolls) arranged along the periphery of the central roll. The flat strip is continuously passed through the five gaps between the central roll and the satellite rolls and formed into a T shape. All rolls are driven at an equal peripheral speed to restrain elongation of strip and to promote transversal metal flow. A guide shoe is provided between each two adjacent satellite rolls to prevent the strip from bulging out or buckling. Using aluminum as a model material, some rolling experiments were performed on the mill. T-shaped profiled strips with a thickness ratio (thickness of thick part per thickness of thin part) as high as three were rolled successfully. When deformation and force characteristics were investigated, it was found that, in comparison to a conventional multipass caliber rolling, the elongation of the strip is suppressed and the filling ability is much improved.

Keywords

deformation and force characteristics, profiled strip, satellite mill, section rolling

1. Introduction

LONG NARROW metal strips with profiled cross sections of which the thickness varies stepwise across the width are used in quantity (Ref 1, 2). The T-shaped profiled copper alloy strip of which the width is more than 50 mm and the thickness ratio (thickness of thick web part per thickness of thin flange part) is about three is especially widely used as raw material for lead-frames of power transistors.

Such profiled strips are usually produced from flat strips by means of various processes (Ref 2, 3). In terms of productivity and yield efficiency, the most advantageous process seems to be continuous rolling. However, this process is not generally applied, because it is difficult to produce a profiled strip free from buckling wave at thin parts.

A new type of compact mill called a "satellite mill" was recently devised by the authors, and it has been applied to continuous rolling of the profiled strips (Ref 4). It has been made clear that the elongation of the strip is suppressed and the filling ability is much improved on the mill, compared with conventional multipass caliber rolling. Therefore, this mill seems to be suitable for the rolling of profiled strips.

In the present paper, new roll passes to form T-shaped profiled strips 50 mm wide with a thickness ratio of three are suggested. The deformation and force characteristics and the product qualities are investigated.

2. Equipment and Rolling Method

Figure 1 schematically represents the layout of rolls in the satellite mill and the method of rolling T-shaped profiled strips. A central roll (350 mm diameter) is accompanied by five satellite rolls (76 mm diameter) arranged along the periphery a specified distance apart. A flat strip is rolled into a profiled strip by passing through the five gaps between the central roll and the satellite rolls. This arrangement constitutes a compact five-stand tandem mill. Each rolling position is referred to as a "stage." All the rolls are driven at an equal peripheral speed to restrain elongation and to promote transversal metal flow. To achieve this, all the satellite rolls are coupled with the central roll by gears, so that only the central roll is driven directly by a motor. To prevent the strip from bulging out or buckling between stages, guide shoes are provided. These guide shoes are connected to the satellite rolls by springs.

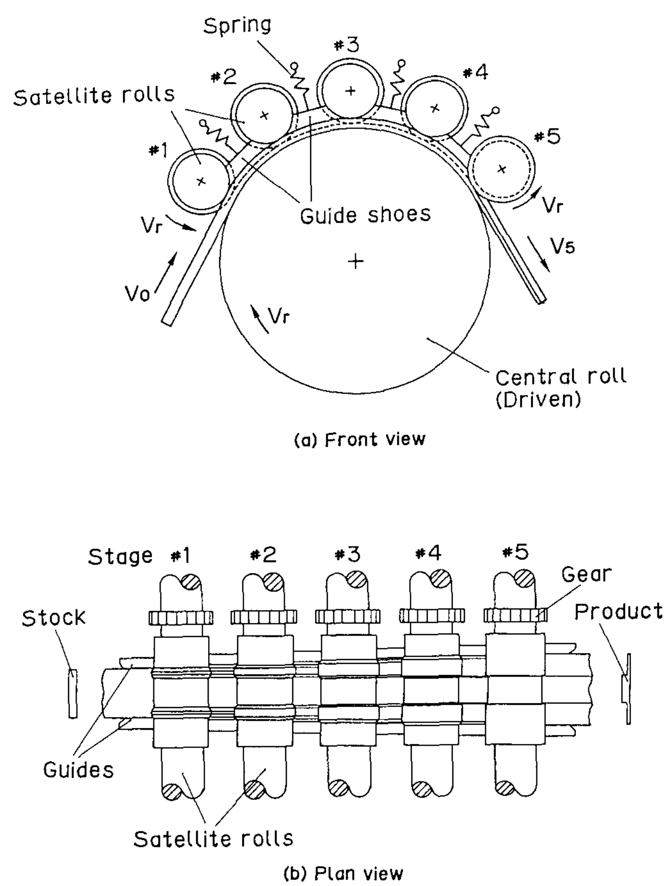


Fig. 1 Basic layout of rolls in the satellite-mill rolling setup

H. Utsunomiya, Y. Saito, T. Hayashi, and **T. Sakai,** Department of Materials Science and Engineering, Faculty of Engineering, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565, Japan.

The profiles and dimensions of roll passes are shown in Fig. 2 and Table 1. Each satellite roll has a pair of projections to form thin parts of the strip. The thick center part of the product is formed in the groove between the projections. The width b and the depth d_1 of the groove are decreased downstream, and the inclination angle of the inner side θ_2 is increased downstream. At the final stage, the width b is 20.0 mm, the depth d_1 is 1.40 mm, and the inclination angle θ_2 is 80°.

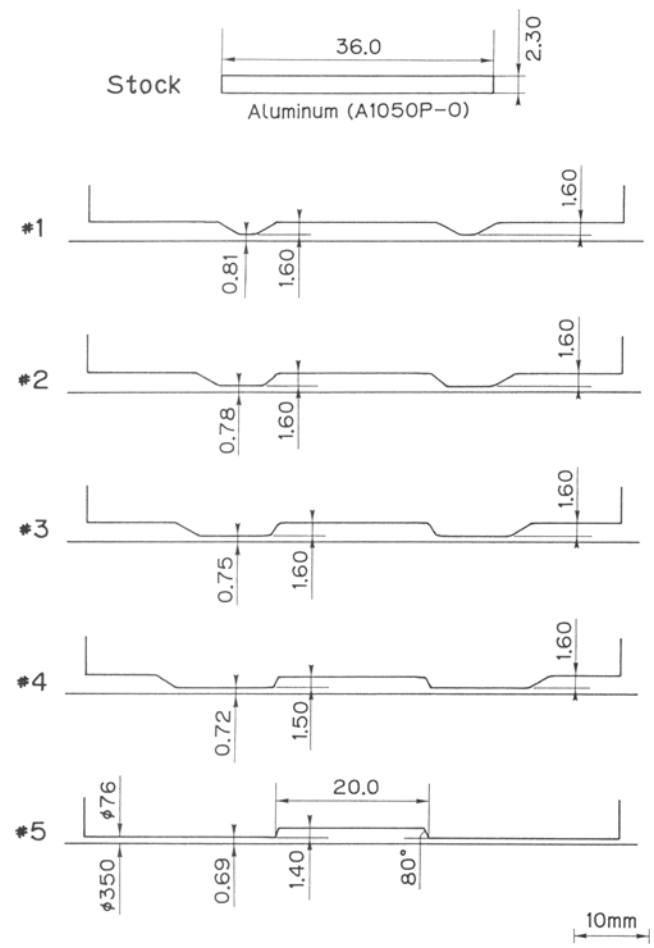


Fig. 2 Roll passes used

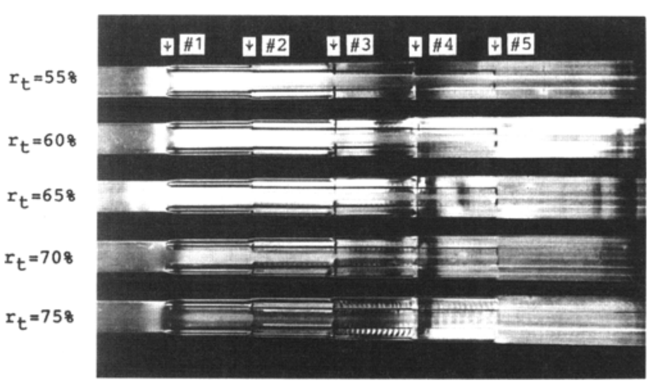


Fig. 3 Plan view of strips under deformation (h_0 = 2.30 mm, w_0 = 36 mm)

At the first stage, two thin parts are formed in the strip. At each following stage, the width of the thin part is widened. Then, at the final stage, the remaining two thick parts at the two edges are rolled and the strip is formed into a T shape. According to the pass schedule shown in Fig. 2, the stock of which the thickness is larger than 2.09 mm is, in principle, formed to the T-shaped profiled strip of which the thickness ratio is three.

3. Experiment

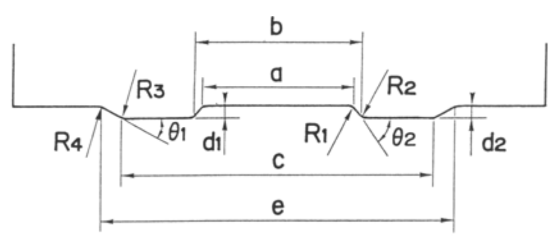
The material as received was a commercially pure aluminum strip (JIS A1050P-O) 2.46 mm thick and 36.0, 38.0, 40.0 mm wide in coil. Prior to the satellite-mill rolling operation, the strips were rolled to 2.20, 2.30, 2.40, and 2.45 mm thick by a two-high flat rolling to investigate the optimum stock dimensions for the roll passes.

With regard to the pass schedule, the drafts of thin part Δh_i were set to 0.03 mm from the second stage to the fifth stage (Fig. 2). The total reduction in thickness of the thin part r_t was varied 55, 60, 65, 70, 75%.

A mineral-oil base rolling oil (IDEMITSU CU-50) was adequately applied to the rolls and the strip. The peripheral speed of all rolls was set equal to 22.0 mm/s. No tension was applied to the strip on either the entering or the delivery side of the mill.

After a steady state of rolling was reached, the rolling operation was interrupted, and the partly rolled strip was taken out of the mill. Then the dimensions, elongation, and forward slip of the strip were measured, and the shape and profile of the strip were observed. The forward slip was determined by a roll mark

Table 1 Specifications of satellite rolls



	a	b	c	d1	d2	e
#1	21.25	26.79	31.00	1.60	1.60	36.54
#2	20.25	23.74	36.00	1.60	1.60	41.54
#3	19.75	21.99	41.00	1.60	1.60	46.54
#4	19.50	20.74	46.00	1.50	1.60	51.54
#5	19.50	20.00		1.40		

	θ1	θ2	R1	R2	R3	R4
#1	30	30	2	3	3	2
#2	30	42.5	2	3	3	2
#3	30	55	1	2	3	2
#4	30	67.5	0.5	1	3	2
#5		80	0.2	0.2		

technique. During the rolling, the roll forces on the satellite rolls and the driving torque of the central roll shaft were measured.

For comparison purposes, conventional two-high five-pass caliber rolling was also conducted under the same rolling conditions. For this purpose, only the third stage of the satellite mill was used, and the satellite rolls were exchanged every pass.

4. Results

4.1 *Optimum Stock Dimensions*

To investigate the optimum stock dimensions for the passes, the stocks of the above-mentioned various dimensions were rolled $r_t = 70\%$. It was found that optimum stock dimensions are 2.30 mm in thickness and 36.0 mm in width. If the stock thickness was 2.20 mm, the metal did not fill the groove at the center part. On the other hand, if the stock was thicker than 2.30 mm, periodic scratches occurred on the web surface. Moreover, if the width of the stock was wider than 36.0 mm, periodic marks due to buckling occurred on the flange surface. The results obtained by using stock 2.30 mm in thickness and 36.0 mm in width are shown in Fig. 3.

Figure 3 shows appearances of rolled strips forming to be T-shaped during the satellite-mill rolling (straightened for observing convenience). If the total reduction r_t was smaller than 60%, the metal did not fill at the web center part. If r_t was larger than 75%, periodic marks occurred on the flange surface of the product.

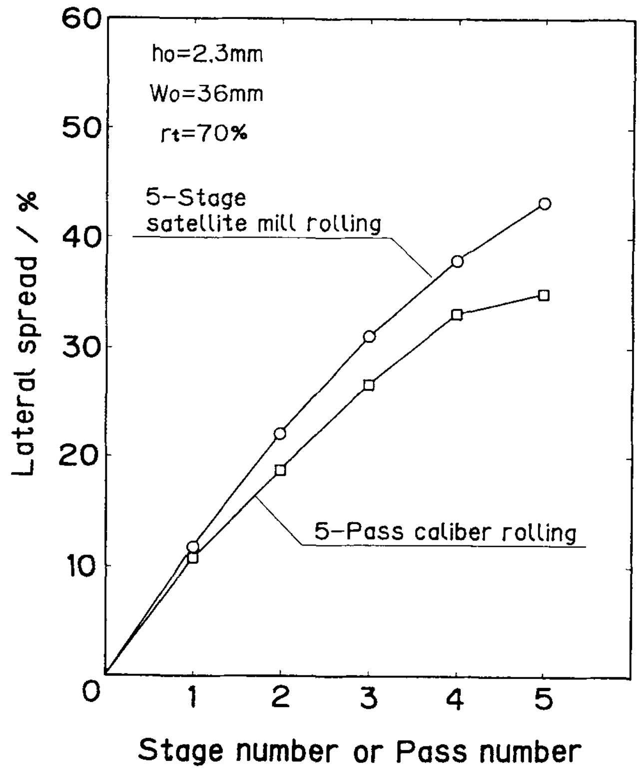


Fig. 5 Variation of lateral spread during rolling

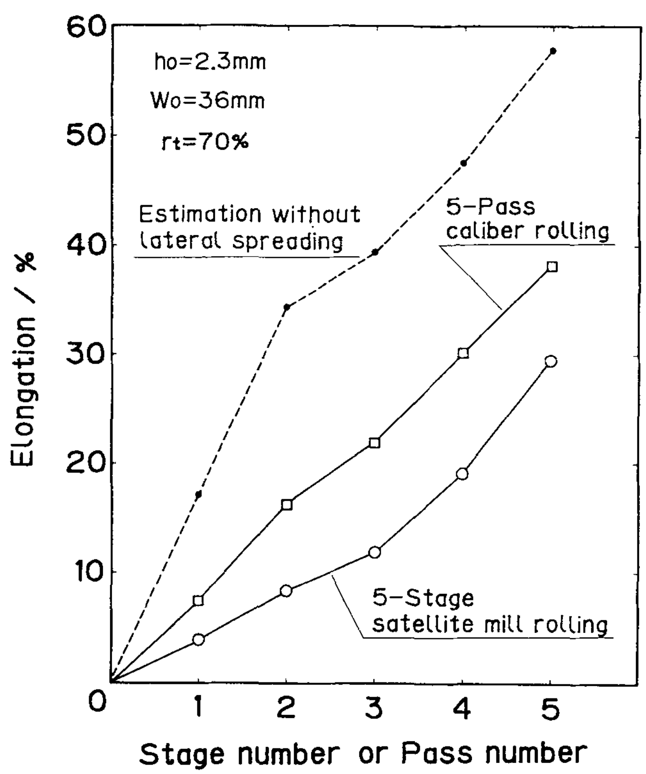


Fig. 4 Variation of elongation during rolling

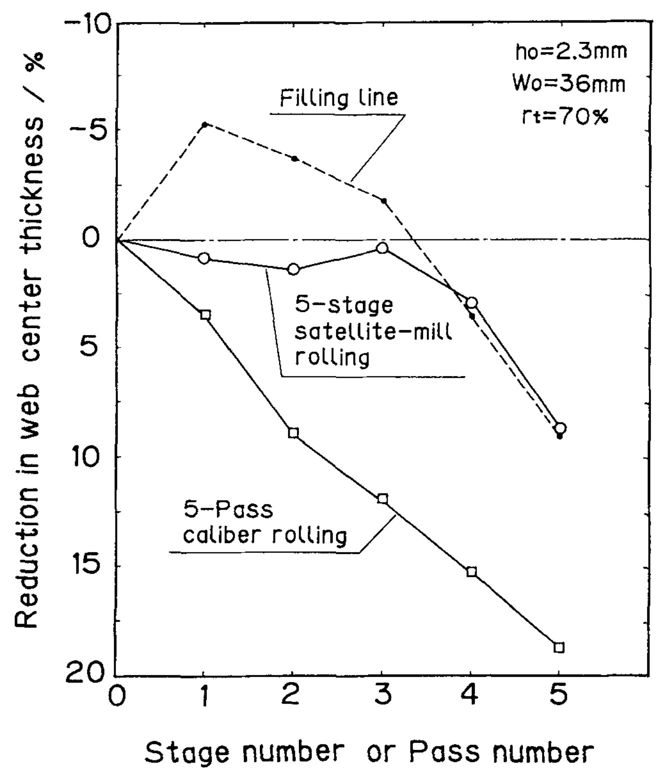


Fig. 6 Variation of reduction in web center thickness during rolling

4.2 *Deformation Characteristics*

The variations of the elongation and the lateral spread during the satellite-mill rolling and the caliber rolling are shown in Fig. 4 and 5, respectively. The elongation of the caliber rolling is increased downstream. The elongation of the satellite-mill rolling are suppressed in the upstream stages. The lateral spread of the satellite-mill rolling is larger than the caliber rolling, and the difference increases toward the exit of the mill. The results mean that in the satellite-mill rolling, at the upstream stages the metal flows toward the groove preferentially, and at the downstream stages the metal flows toward the edges.

The variations of the thickness at the web center are compared similarly in Fig. 6. In the caliber rolling, the web center thickness is decreased with the progress of the rolling. In the satellite-mill rolling, the web center thickness decreases slightly at the first and second stages, increases at the third stage, and fills up the groove and is reduced by rolls at the fourth and fifth stages.

The variations of the strip cross sections during the satellite-mill rolling and those during the caliber rolling are observed in Fig. 7. The enlarged profiles of the products are shown in Fig. 8. In the caliber rolling, cavities remain at the web center of the satellite roll side and at the corner of the

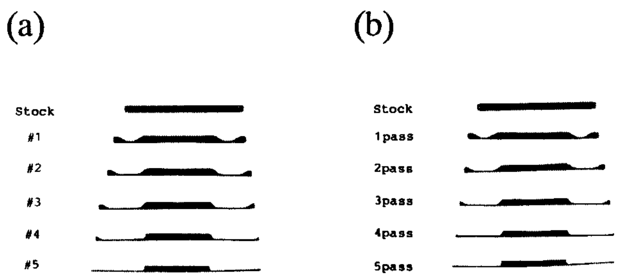


Fig. 7 Cross sections of strips before rolling and after passing each stage of satellite-mill rolling or each pass of caliber rolling: (a) five-stage satellite-mill rolling, (b) five-pass caliber rolling

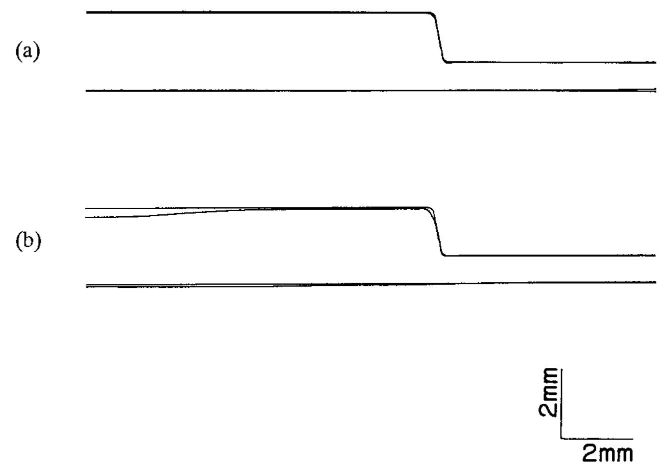


Fig. 8 Enlarged cross sections of products: (a) five-stage satellite-mill rolling, (b) five-pass caliber rolling

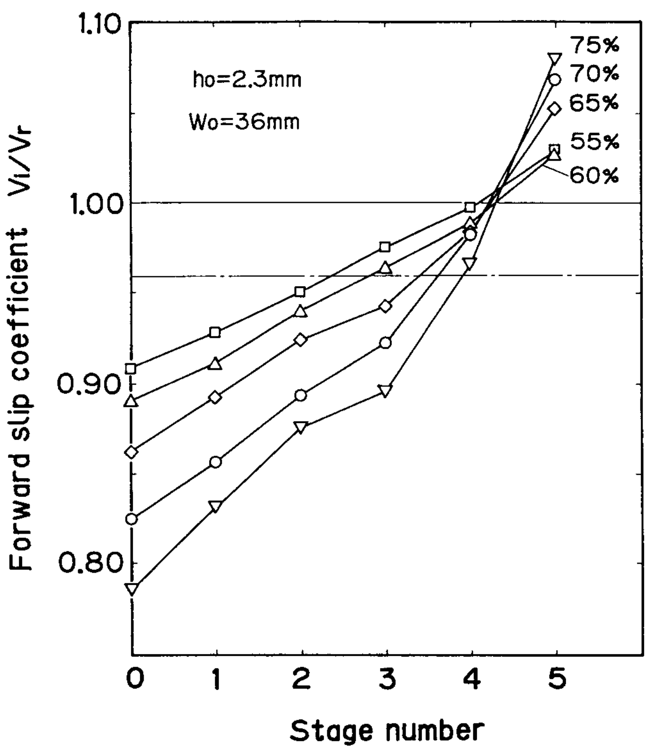


Fig. 9 Variation of forward slip coefficient during satellite-mill rolling

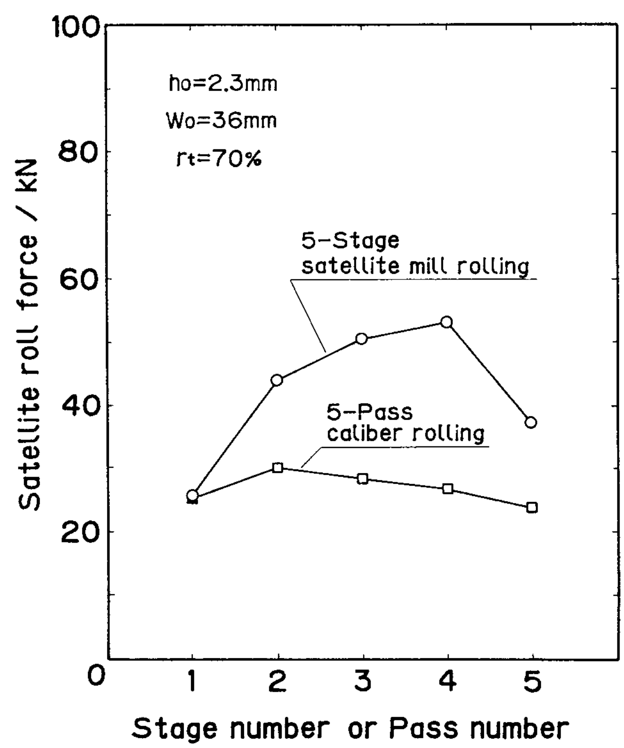


Fig. 10 Distribution of satellite roll force during rolling

groove. On the other hand, in the satellite-mill rolling, the grooves are filled completely.

4.3 *Forward Slip Characteristics*

The forward slip coefficient (the speed of the flange at the delivery side of each stage normalized by the roll peripheral speed) is shown in Fig. 9. A dot-dash line indicates the average roll peripheral speed at the bottom of the groove. Referring to the dot-dash line, the neutral point exists at the third stage in case r_t is smaller than 60%, and it exists at the fourth stage in case r_t is larger than 60%. The neutral point shifts downstream with increasing r_t.

4.4 *Force Characteristics*

The distribution of the satellite roll forces during the satellite-mill rolling and those during the caliber rolling are compared in Fig. 10. The roll forces during the caliber rolling are relatively uniform. The roll forces during the satellite-mill rolling are one to two times higher than those during caliber rolling. The roll forces during the satellite-mill rolling show the "friction hill"-like distribution having a peak at the fourth stage. The position of the peak corresponds to the position of the neutral point in Fig. 9. This means that the interstage compression due to equal roll speed increases toward the neutral point.

4.5 *Product Qualities*

4.5.1 Accuracy of Thickness

The thickness distribution through the width of the strip produced by the satellite-mill rolling (r_t = 70%) is plotted in Fig.

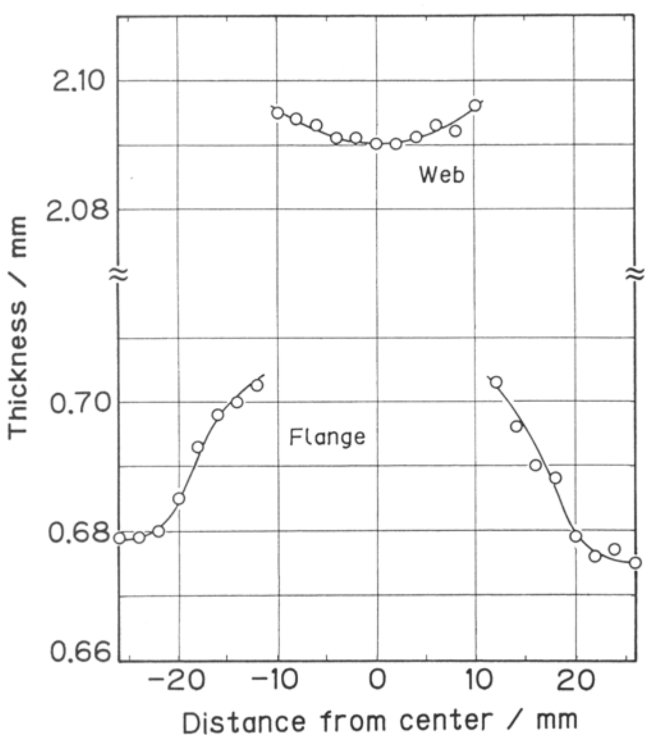


Fig. 11 Thickness distribution of strip produced by satellite-mill rolling (r_t = 70%)

11. In the flange part, the strip crown is 0.02 mm, 3%. This crown seems to be caused by the elastic deformation of the rolls. However, the edge drop does not occur because, in the fifth stage, the thick edges are flattened. In the web part, the thickness of the center part is decreased about 5 μm, 0.2%.

4.5.2 Hardness Distribution

The micro Vickers hardness distribution in the half cross section of the strip produced by the satellite-mill rolling (r_t = 70%) is shown in Fig. 12. One peak is located in the vicinity of the step. The other peak is located at the edges. The hardness shows minimum at the center of the web.

4.5.3 Macrostructure

The macrostructures of the step and the edge parts are observed in Fig. 13. The projected edge of the thick part cannot be seen because of the etching. Severe grain flows occur in the vicinity of the step in the flange part and at the edge part. These grain flows correspond to the peaks of hardness in Fig. 11.

4.5.4 Surface Defects

In Fig. 13(a), a slight overlapping defect can be observed on the flange surface of the satellite roll side in the vicinity of the

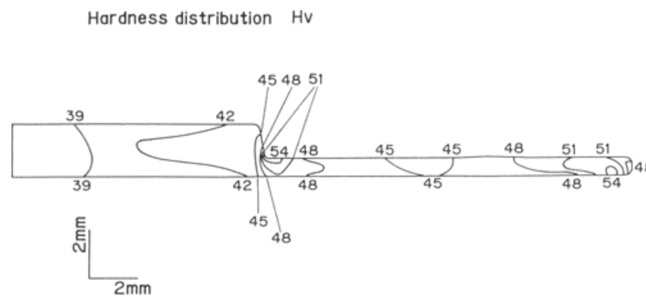


Fig. 12 Micro Vickers hardness distribution in half cross section of strip produced by satellite-mill rolling (r_t = 70%)

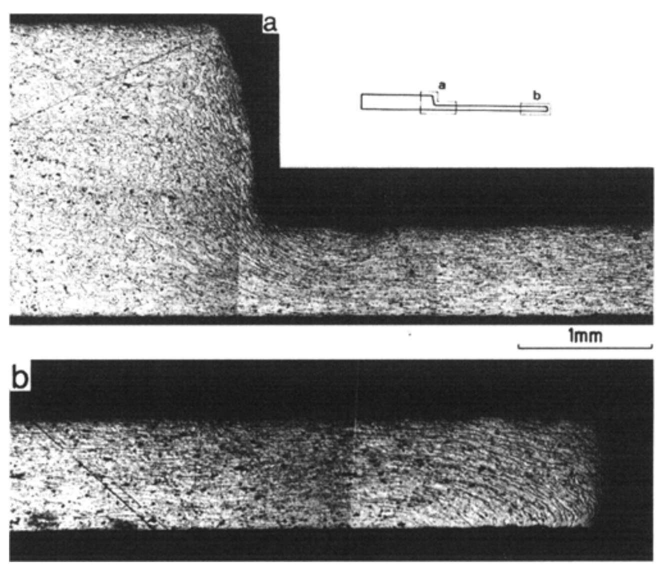


Fig. 13 Macrostructure in cross section of the strip produced by satellite-mill rolling (r_t = 70%)

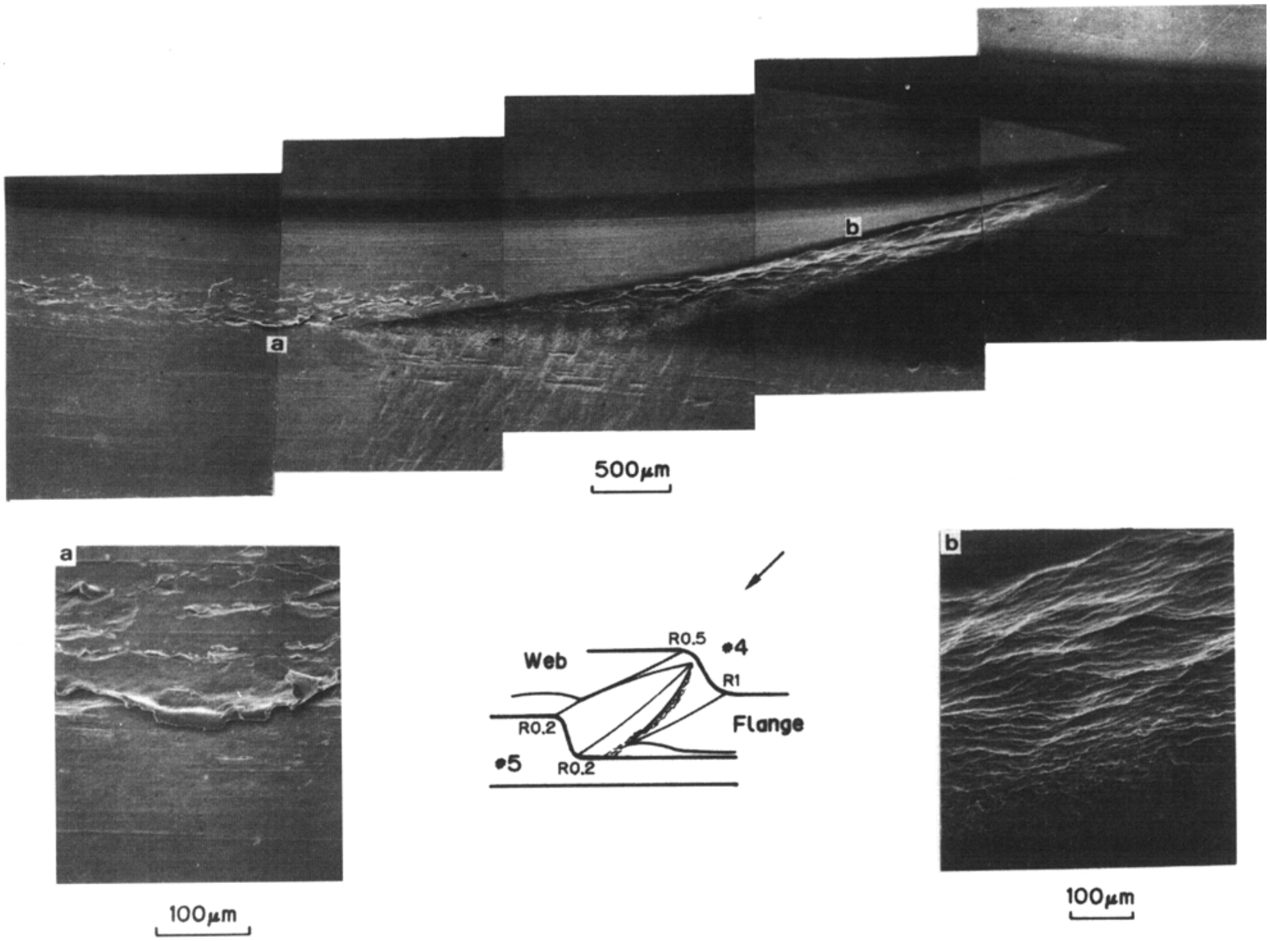


Fig. 14 SEM image of strip surface under deformation in roll bite of fifth stage of satellite mill

step. To investigate the mechanism of the defect formation, the surface of the fifth roll bite is observed by scanning electron microscopy (SEM) in Fig. 14. It is clear that, as the 67.5° slope of the step that was formed at the fourth stage is being rolled, the free surface is roughening (b), which leads to overlapping defect at the exit of the stage (a).

5. Discussion

The foregoing results clearly show that, in the satellite-mill rolling, the elongation is suppressed, the lateral spreading is promoted, and the roll force is enhanced. These effects can be explained consistently if a longitudinal compressive stress between stages is assumed (Ref 4). The stress is due to equal roll speed, and it increases toward the neutral point. Therefore, this stress assists the metal to flow transversely in the roll bite and enables the efficient forming of a profiled strip from a flat strip. It is clear that T-shaped profiled strip 52 mm wide with a thickness ratio of three can be rolled continuously on the satellite mill with the suggested roll passes.

The optimized stock dimensions for the roll passes were found to be 2.30 mm in thickness and 36 mm in width. If the stock is thinner than 2.30 mm, the total reduction r_t is decreased, and the metal does not fill up the groove. On the other hand, if the stock is thicker, the larger reduction is needed, the groove is filled upstream, and consequently the scratch occurs in the thick part. A wider stock reduces transverse flow and promotes the buckling of the thin part. After all, it is found that the optimization of the stock dimensions for the passes is important.

With regard to the hardness distribution of the product, two peaks exist at both ends of the flange part. At these regions, severe grain flows are observed. Therefore, it is clear that local severe deformation occurs in the regions. And the slight overlapping defect occurs in the vicinity of the corner. It is found that the defect is caused by roughening of the free surface. So it seems to be restrained by the optimization of the roll pass design or use of a stock having finer grain size.

6. Conclusions

The T-shaped profiled strip with a width of 52 mm and a thickness ratio of three is produced successfully on the satellite mill with the suggested roll passes. The following results were obtained.

- In the satellite-mill rolling, the elongation is suppressed, and the filling ability is much improved. However, the roll forces are one to two times higher than those of the conventional caliber rolling.

- The hardness distribution in the product cross-section has two peaks, which are located at the both ends in the thin flange part. In these regions, severe grain flows are observed. The slight overlapping defects occur in the vicinity of the step in the thin part.

References

1. G. Tembe, Profiled Metal Strips Trim Production Costs, *Eng. Mater. Des.*, (No. 1), 1972, p 13-16
2. H. Fukuda, Manufacturing Process and Application of Profiled Metal Strips, *J. Jpn. Soc. Tech. Plast.*, Vol 32 (No. 363), 1991, p 452-457 (in Japanese)
3. H. Abe, K. Ishida, K. Furuichi, and T. Matsui, Contour Copper Strips for Semiconductive Leadframe by New Rolling Process, *Hitachi Cable Review*, (No. 5), 1986, p 45-48
4. Y. Saito, T. Watanabe, and H. Utsunomiya, Development of Satellite Mill and Trial Rolling of Profiled Metal Strip, *J. Jpn. Soc. Tech. Plast.*, Vol 33 (No. 376), 1992, p 567-572 (in Japanese)