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T-bar rolling process with universal and edger mills

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Abstract

Use of T-bars in shipbuilding has increased recently. Although T-bars having a web height of at least twice the flange width are generally required for ships, the dimensions of existing hot-rolled T-bars are not suitable. As a result, T-bars for ships are typically fabricated by welding two plates. To solve this problem, a new rolling method for T-bars using a universal mill and edger mill was investigated. Finite element analyses of universal and edger rolling were executed to investigate the characteristics of side camber. Next, multi-pass rolling experiments simulating the rolling passes at a universal roughing mill and an edger mill were performed, and straight pure lead T-bars having satisfactory cross sections were obtained. However, the web heights at the top and tail ends were larger than those of the other part. Additional vertical rolls were applied to edger rolling to enable a slight reduction of the web height, and the web height deflection was eliminated by this new arrangement. The results of this research clearly demonstrated the potential of the new rolling process for producing T-bars of ships.

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Keywords: Section rolling; Model experiment; Finite element analysis; Side camber; Rolling deformation

1. Introduction

T-bars are used for many kinds of structures, and can be manufactured by several rolling methods using structural mills. For example, hot rolling with groove rolls has been used for many years. Beynon (1956) presented a typical roll pass design for T-bars, and Brayshaw (1958) showed more examples including special T-sections. Three-roll mills are sometimes applied to T-bar production. For example, Kyoi et al. (1978) studied the fundamental deformation behavior in three-roll rolling of T-bars. However, the web height of T-bars produced by

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this method is smaller than that with other methods. Another method of producing T-bars is to slit H-beams, and many T-bars are now made in this way.

Recently, the use of T-bars in shipbuilding is increasing, but the dimensions of hot rolled and slit T-bars are not suitable for this application, as T-bars having a web height of at least twice the flange width are generally required for shipbuilding, while the ratio of the web height to flange width of hot rolled and slit T-bars is less than two. As a result, T-bars for ships are typically fabricated by welding two plates.

A Japanese patent by Hirayo et al. (1968) presented a unique approach to T-bar rolling using a universal mill for H-beam rolling. The web of the T-bar is rolled with the horizontal rolls, and the flange is rolled between a vertical roll and the side surfaces of the horizontal rolls. The flange width is controlled with an edger mill installed near the universal mill. The edger rolls also have the same configuration as for H-beam rolling.

This method offers many advantages. First, slim T-bars suitable for shipbuilding can be rolled. Second, T-bars having different outer dimensions and thicknesses can be produced with the same pair of horizontal and vertical rolls, making it possible to expand the variety of product sizes without increasing the roll cost. However, this universal rolling method has not been examined since the patent was published, probably because the asymmetric rolling shape that lacks one flange of an H-beam was expected to produce large side camber in universal rolling.

To assess the possibility of T-bar universal rolling, Takashima and Hiruta (2012) carried out experimental and numerical studies simulating this universal rolling method to investigate the basic rolling deformation in asymmetric universal rolling, including side camber, and demonstrated the possibility of this novel method.

In the present study, a T-bar rolling process using universal and edger mills was investigated for the production of T-bars in an actual production line. Finite element analyses of universal and edger rolling were executed to investigate the characteristics of side camber. Next, a series of reduced-scale laboratory rolling experiments was carried out with pure lead as a model material. Multi-pass rolling experiments simulating the rolling passes with a universal roughing mill and an edger mill were carried out.

2. Process overview

The mill layout for the investigation of the T-bar rolling process was determined based on a common arrangement for H-beam rolling as shown in Fig. 1. The break down mill forms the initial rectangular-section workpiece into a rough T-section bar. Next, a universal roughing mill and an edger mill are used to reduce the web and flange thicknesses and the flange width. Finally, a finishing universal mill is used to straighten the flange shape. Figure 2 shows images of the cross sections after break down and Universal Roughing-Edger rolling.

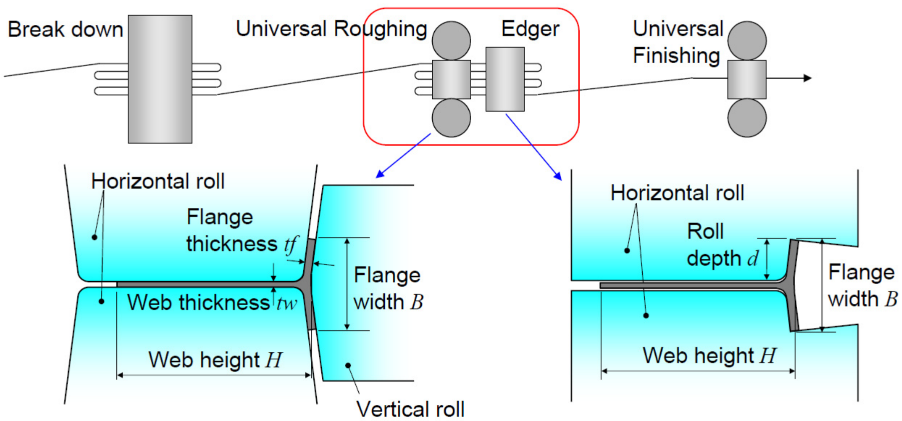

Fig. 1. Mill layout of T-bar rolling and schematic diagrams of Universal Roughing and Edger rolling.

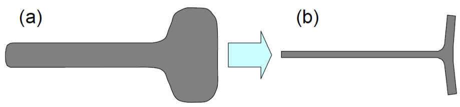

Fig. 2. Images of sections in the T-bar rolling process (a) after break down rolling, (b) after Universal Roughing-Edger rolling.

A common groove rolling method for T-bars can be applied to break down rolling. Universal finishing rolling changes the flange angle slightly with one pass rolling and thus is not expected to be difficult. However, the deformation in Universal Roughing-Edger multi-pass rolling has not been studied. Therefore, the Universal Roughing-Edger rolling passes were investigated.

3. FE analysis

In order to investigate the side camber behavior in Universal Roughing-Edger passes, non-steady-state FE analyses were performed for both universal and edger rolling. A three-dimensional numerical simulation was conducted with a dynamic explicit FE code, ABAQUS Explicit ver.6.12. First, the influence of web thickness *tw* and flange thickness *tf* on the grade of side camber in universal rolling was investigated. Considering the mirror symmetry of the T-bar cross section, a half part of a T-bar was modeled for the simulation. The initial length of the T-bar was set at 1500mm. Three T-bar cross sections corresponding to a later pass: tw10, a middle pass: tw20 and an early pass: tw30 of universal rolling were designed as shown in Fig. 3. Solid brick reduced integration elements were used for the T-bar, and the element number was approximately 150,000 to 180,000. The rolling conditions were a web thickness reduction r_w of 15% and flange thickness reduction r_f of 18%. This means that the difference of thickness reductions (r_f - r_w) was 3%, which was reported to be the suitable condition for side camber prevention. The horizontal rolls (diameter: 900mm) were driven, and the vertical roll (diameter: 700mm) was undriven.

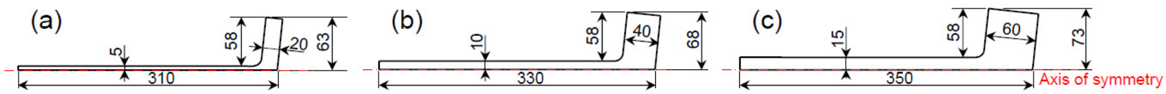

Fig. 3. Sections for FE analysis: (a) tw10, (b) tw20, (c) tw30.

FE simulation of edger rolling was also executed with the section in Fig. 3(b) to investigate the influence of flange width reduction on side camber. The flange width *B* before rolling was 136mm, and the flange width reduction *ΔB* was set to 2, 4 or 6 mm in the edger rolling simulation.

The curvature of side camber was calculated by least squares from the data of node coordinates on the flange outside center line. The results are shown in Fig. 4. In universal rolling, flange-side camber occurred, and thicker sections had larger curvatures. On the contrary, web-side camber occurred in edger rolling, and larger flange width reductions caused larger curvatures. These tendencies of side camber were used in determining the design of rolling facilities and the draft schedule for Universal Roughing-Edger multi-pass rolling.

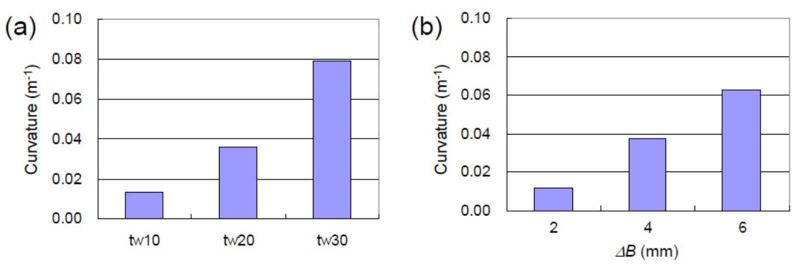

Fig. 4. Curvatures of side camber by FE simulation: (a) three sections of universal rolling, (b) three edger rolling conditions.

4. Model experiment of Universal Roughing-Edger rolling

4.1. Experimental setup

Based on the FE simulation results, a series of reduced-scale laboratory rolling experiments of multi-pass Universal Roughing-Edger rolling was arranged. A laboratory universal mill and a laboratory edger mill having the same roll configurations as Fig. 1 were prepared. A constant reduced-scale of one-fifth was assumed, and pure lead was used as the model material. In the FE analysis of edger rolling, the workpiece always caused web-side camber. To restrict this web-side camber, a pair of guides supporting the flange inside and web surfaces was arranged at the exit side of the edger mill as shown in Fig. 5. The same guides were also set in the universal mill.

The diameter of the horizontal roll was 180mm and that of vertical roll was 140mm. The dimensions of the initial workpiece web thickness, flange thickness, web height and flange width were 8, 16, 68 and 30mm, respectively.

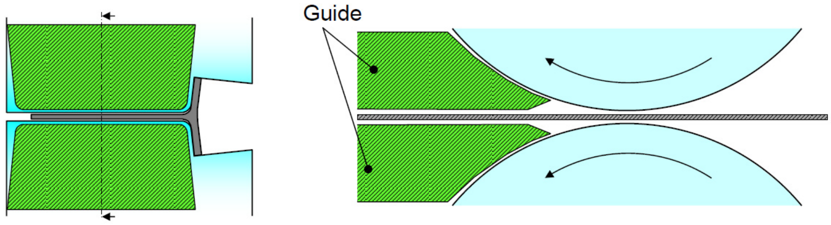

Fig. 5. Geometry and position of guide.

4.2. Experimental conditions

The FE simulation of universal rolling showed the influence of thickness on the grade of side camber. This property was considered in the experiment, but it was difficult to expect suitable thickness reductions of the web and flange in each universal rolling pass. Therefore, the initial draft schedule of universal rolling was determined by setting the web and flange thickness reductions as 15% and 18%, respectively. The edger roll gap was decided based on web thickness and roll clearance to the web. The clearance was set to 0.1mm, and the groove depth of the edger roll at flange tip was designed as 11mm. This meant that the target flange width of edger rolling became web thickness plus 22.2mm. Based on these conditions, the draft schedule of the multi-pass rolling experiment was determined as shown in Table 1.

Table 1. Draft schedule of T-bar Universal Roughing-Edger rolling experiment

Pass No.	U-1	E-1	U-2	U-3	E-2	U-4	U-5	E-3	U-6	U-7	E-4	U-8	U-9	E-5	U-10	U-11
Web thickness /mm	7.4		6.5	5.7		5.0	4.4		3.9	3.4		3.0	2.6		2.3	2.0
Flange thickness /mm	14.4		12.4	10.5		9.1	7.7		6.6	5.6		4.8	4.1		3.5	3.0
Flange width /mm		29.6			27.9			26.6			25.6			24.8		

4.3. Result of experiment

Similarly to the FE simulation results, universal rolling in the early passes caused larger flange-side camber in this experiment. To decrease the grade of flange-side camber, the flange thickness reductions of these passes were increased, and several workpieces were examined. Web-side camber was observed in edger rolling, but the camber was restricted by the guides and did not cause any serious problems in the following universal pass. All pass numbers in Table 1 were satisfactorily completed with the increased flange thickness reduction.

To investigate the side camber behavior in detail, the grade of side camber was measured in all passes. A side camber of 100mm length at the middle of the flange outer side was measured with a depth gauge. The side camber data are shown in Fig. 6. It can be seen that large flange-side cambers occur in the U-2 and U-3 passes. The difference of thickness reductions (r_f - r_w) in universal rolling is also plotted in the same graph. In spite of the large (r_f - r_w) of the U-3 pass, the direction of the side camber was still to the flange side.

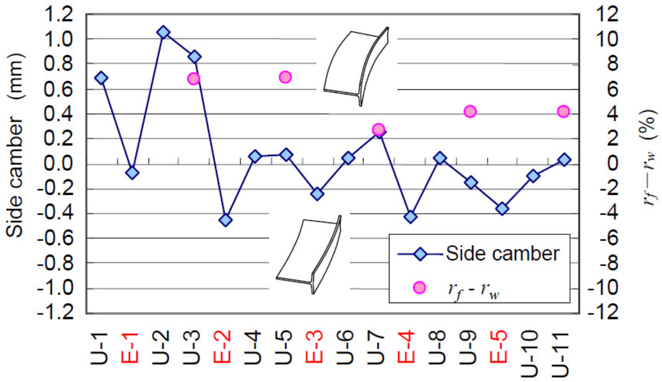

Fig. 6. Side camber and thickness reduction difference.

The appearance of a rolled T-bar top end after the U-11 pass is shown in Fig. 7(a). A straight pure lead T-bar was obtained, but the maximum web height at the top and tail parts was 65.4mm, which was about 10mm wider than that of the middle part. A cross section of the workpiece at the center of length is shown in Fig. 7(b). The cross section satisfies the target dimensions except web height. Although its web height, 55.3mm, was smaller than the dimension corresponding to a T300 × 125 T-bar, the web height of the rolled T-bar can be increased by changing the web height of the initial rough T-bar. Thus, the problem of small web height will be solved easily.

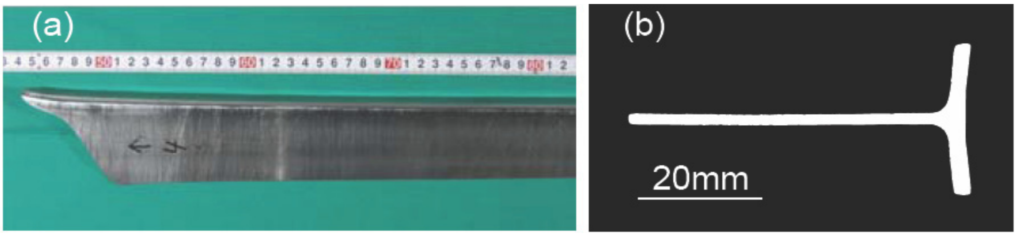

Fig. 7. Rolled pure lead T-bar: (a) appearance of top end, (b) cross section at center of length.

The multi-pass rolling experiment clearly demonstrated the possibility of this new T-bar rolling process. However, some problems remained to be solved in order to realize better productivity and dimensional accuracy. First, the large flange-side camber in early universal rolling passes should be decreased, and second, the increased web heights at the top and tail ends required a solution.

According to Takashima and Hiruta (2012), flange-side camber was prevented by applying a vertical side guide plate along the flange outer side at the universal mill exit side. Therefore, a vertical side guide along the flange outer side was added in universal rolling for flange-side camber prevention. For the problem of web height deflection at the top and tail ends, some web height reduction, like the flange width with the edger mill, was considered as a solution. To realize this idea, a new roll arrangement of the edger mill with additional vertical rolls was developed, as shown in Fig. 8, and another multi-pass rolling experiment was carried out with these facilities.

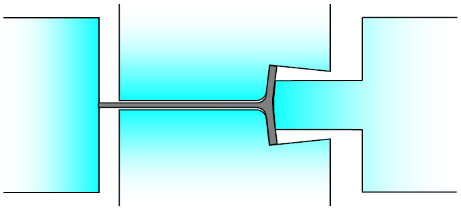

Fig. 8. Arrangement of new edger with vertical rolls.

5. Model experiment with new facilities

Although flange-side camber was observed at the top end in universal rolling, the new vertical side guide restricted this flange-side camber, and the rolled workpieces were straight except at the top end. The side camber in the U-2 and U-3 passes clearly decreased from the former experiment. In addition, the differences of thickness reductions (r_f-r_w) of these passes were decreased, which increased the stability of the universal and edger passes.

A slight web height reduction was given in the edger rolling passes with the new vertical rolls. At the end of the new experiment, a straight pure lead T-bar was obtained again. The shape of the top part of the rolled workpiece is shown in Fig. 9(a). The web heights at the top and tail ends were successfully decreased to the same dimensions as the other part. A cross section of the T-bar at the center of length is shown in Fig. 9(b). The cross-sectional dimensions satisfactorily agreed with the target values except web height. Web height reduction provided one more advantage in the cross section geometry, namely, the web tip became flat and right-angled with respect to both web surfaces. Thus, the new edger produced a suitable cross section for welding with plates in shipbuilding.

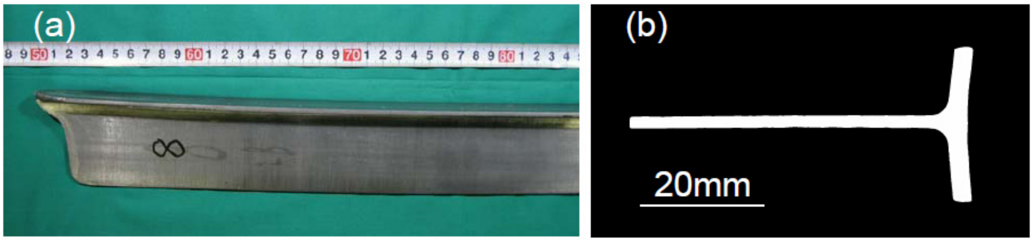

Fig. 9. Pure lead T-bar rolled with new facilities: (a) appearance of top end, (b) cross section at center of length.

6. Conclusion

A new rolling method for T-bars using a universal mill and edger mill was investigated numerically and experimentally. Side camber behavior in universal and edger rolling was clarified by FE simulation. Multi-pass rolling experiments of UR-E rolling were carried out, and straight pure lead T-bars having excellent cross-sectional geometries were successfully obtained after some improvements of the rolling facilities. Consequently, the potential of the new rolling process for producing T-bars of ships was clearly demonstrated.

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