KAWASAKI STEEL TECHNICAL REPORT
No.37 (October 1997)
Rolling Technology and Modernization of Chiba Works

Endless Hot Strip Rolling in the No. 3 Hot Strip Mill at the Chiba Works

Hideyuki Nikaido, Shigeru Isoyama, Nobuaki Nomura, Kanji Hayashi, Kazuo Morimoto, Hideo Sakamoto

Synopsis :
Fully continuous finishing rolling, so called "endless hot strip rolling", started at No. 3 hot strip mill in Chiba Works of Kawasaki Steel for the first time in the world, depending on the development of sheet bar joining process and establishment of continuous rolling system. For joining the head and tail ends of sheet bars, an induction heating and an upsetting method was adopted. This method made it possible to join the sheet bar ends in a short time, like 5 s. Strength of joint is equal to its mother materials and no scale residue was found accross the joint. Accordingly, an ideal joining technology was established. Sheet bar ends are joined before reaching the finishing mill while the bar moving. Continuous finishing hot strip rolling is performed under an uninterrupted tension between rolling stands. As a result, product quality, like thickness accuracy, productivity and stability of rolling were extremely improved. In addition, ultra-thin strip and thin-wide strip have been able to be produced without trouble.

Endless Hot Strip Rolling in the No. 3 Hot Strip Mill at the Chiba Works*



Hideyuki Nikaido
Dr. Eng., Staff Manager, Hot Rolling Technology Sec., Hot Rolling Dept. and Equipment Technology Sec., Equipment Technology Dept., Chiba Works

Shigeru Isoyama
Staff Manager, Equipment Technology Sec., Equipment Technology Dept., Chiba Works

Nobuaki Nomura
Staff Manager, Hot Rolling Technology Sec., Hot Rolling Dept., Chiba Works



Kanji Hayashi
Manager, Rolling Mill Plant Sec., Steel Manufacturing Machinery Designing Dept., Mitsubishi Heavy Industries, Ltd.

Kazuo Morimoto
Engineering Manager, Machinery Plant Lab., Mitsubishi Heavy Industries, Ltd.

Hideo Sakamoto
Assistant Manager, Industrial Apparatus Design Sec. II, Industrial Apparatus Dept., Transmission & Distribution, Transportation Systems Center, Mitsubishi Electric Corp.

Synopsis:

Fully continuous finishing rolling, so called "endless hot strip rolling", started at No. 3 hot strip mill in Chiba Works of Kawasaki Steel for the first time in the world, depending on the development of sheet bar joining process and establishment of continuous rolling system. For joining the head and tail ends of sheet bars, an induction heating and an upsetting method was adopted. This method made it possible to join the sheet bar ends in a short time, like 5 s. Strength of joint is equal to its mother materials and no scale residue was found accross the joint. Accordingly, an ideal joining technology was established. Sheet bar ends are joined before reaching the finishing mill while the bar moving. Continuous finishing hot strip rolling is performed under an uninterrupted tension between rolling stands. As a result, product quality, like thickness accuracy, productivity and stability of rolling were extremely improved. In addition, ultra-thin strip and thin-wide strip have been able to be produced without trouble.

1 Introduction

Usually, batch rolling, which involves the rolling of sheet bars one by one, is conducted in the finish rolling process of a hot strip mill. In batch rolling, the head and tail ends of a strip are rolled in an unstable state without tension. This causes various problems to occur, such as deterioration of product quality, decrease in yield and hindrance of threading.

An apparent solution to these problems is a process called endless rolling. In endless rolling, finish rolling is continuously conducted by joining sheet bars on the entry side of the finishing mill. In the continuous rolling on a hot strip mill, however, there are many difficult challenges, such as the development of joining techniques and building of a continuous rolling system covering the entire hot strip mill[1].

At the Chiba Works of Kawasaki Steel, research and development of joining techniques was started in 1990 in anticipation of the incorporation of the endless rolling process in the operation of the No. 3 hot strip mill that was planned at the time. As a result, an induction-heating joining technique for joining sheet bars in a short time was developed and endless rolling was startd at the beginning of 1996. This report describes the process and results of endless rolling in the No. 3 hot strip mill.

2 Problems with Batch Rolling

The following problems exist with finish rolling in the

* Originally published in *Kawasaki Steel Giho*, **28**(1996)4, 224–230

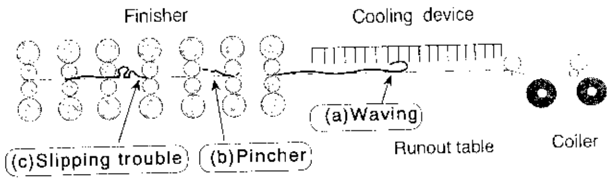

Fig. 1 Problems of the usual "batch process"

conventional batch process in hot strip rolling (**Fig. 1**).

(1) Because the rolling of the head and tail ends of sheet bars is conducted in an unstable state without tension, irregularities in strip thickness, strip crown, shapes, etc., tend to occur, causing quality deterioration and a decrease in yield.

(2) Pinchers are apt to occur in the rolling of the tail end of a thin strip. When pinchers occur, the rolls are damaged and it becomes necessary to change them, reducing productive time and increasing the roll grinding cost. With the present rolling thchniques it is difficult to completely solve the pincher problem so production is plagued to some extent by such troubles.

(3) When the threading speed for the head end is increased, the sheet bar on the hot run table may jump greatly, making it impossible to increase the threading speed sufficiently[2]. For this reason, productivity cannot be raised adequately in the rolling of thin strips.

The following problem related to the development and production of products of better quality exists in addition to the above problems which the operators of a hot strip mill face:

(4) Because lubrication cannot be conducted from the head end in order to prevent defects when the head end enters the roll gap in lubricated rolling, the sheet bar cannot be lubricated along its full length.

3 Objectives and Technical Challenges of Endless Rolling

3.1 Objectives of Endless Rolling

The objectives of endless rolling are to solve the problems with batch rolling mentioned in Chapter 2 and to surpass the limits of batch rolling. These objectives can be broadly divided into the following four areas:

(1) Stabilizing quality and increasing yield by eliminating the parts of the strip rolled in an unstable state,

(2) Stabilizing production and increasing productivity in the rolling of thin strips,

(3) Production of thin-wide strips and ultra-thin strips that surpass the rolling limits of conventional thin strips,

(4) Production of new products by lubricated rolling or rolling with forced cooling.

These objectives are described in detail below.

3.1.1 Quality stabilization and increase in yield

Finish rolling is conducted by joining about 10 sheet bars in endless rolling. Applied tension is maintained throughout the process from the finishing mill to the coiler except for the head end of the first sheet bar and the tail end of the last sheet bar, enabling rolling and threading to occur in an ideal condition without shape disturbance.

Therefore, the accuracy of gauge and temperature control improves greatly and variations in the gauge and width of the head end rarely occur. Furthermore, the defective dimensions and shapes that were observed in the roughly 150 m long portion rolled while the head end reaches the coiler and the same length portion rolled after the tail end leaves the finishing mill, as well as the quality imperfections caused by unsteady rolling, scarcely occur in endless rolling.

3.1.2 Stable production of thin products and increase in productivity

Usually, strips of not more than 1.8 mm and not less than 1.2 mm in thickness that are produced in a hot strip mill are called thin products. In the production of thin products, the jumping of the head end of a sheet bar on the hot run table called waving ((a) of Fig. 1) and the pincher (b) that occurs when the tail end leaves the finishing mill have often posed problems. Furthermore, the strip speed of the head end is limited to about 800 m/min to prevent waving. In terms of productivity, it is desirable to increase the strip speed by about 20%.

In endless rolling, all head ends and tail ends are joined. Therefore, there is no possibility of waving or pinching and the strip speed near the joined ends corresponding to the head end in batch rolling is more than 1 000 m/min. This makes it possible both to stabilize rolling and to increase the productivity of thin products, which has been almost impossible in batch rolling.

3.1.3 Production of thin-wide and ultra-thin products

One of the greatest objectives of endless rolling is the stable production of thin-wide and ultra-thin products, which has been almost impossible in conventional hot strip rolling. For example, the minimum thickness of strips produced by hot rolling is limited to 1.2 mm and the maximum strip width is limited to 1 250 mm. If strips of a size outside these ranges are batch rolled, problems may arise that cause more than 10% of the threading of the head and tail ends to be unsuccessful meaning that commercial production is essentially impossible.

In endless rolling, it is possible to roll bars in a stable condition with tension applied throughout from the head end to the tail end, which is impossible in batch rolling. Therefore, strips up to 1 600 mm in width can be produced if the strip thickness is 1.2 mm and strips 0.8 mm in thickness can be produced if the strip width does not exceed 1 250 mm.

3.1.4 Stable production of new materials by lubricated rolling and rolling with forced cooling

Strips with excellent properties can be produced if lubricated rolling is conducted in hot strip rolling[3]. However, the range of stable lubrication is limited to the middle portion of one coil in order to prevent slipping when the head end enters the roll gap caused by the injection of lubricating oil, which is shown in Fig. 1 (c). Hence the problems of unstable quality and low yield exist.

In endless rolling that involves the continuous rolling of about 10 sheet bars, lubrication can be continued for a long time till the last bar passes through the finishing mill. Therefore, lubrication can be conducted in a stable manner while the decrease in yield is almost negligible.

The same can also be said for the forced cooling on the hot run table on the delivery side of finishing mill. In endless rolling, tension is constantly applied to the strip on the hot run table, so the problems of threading and nonuniform cooling do not occur and fully homogenous strips can be obtained even if very strong cooling is conducted.

3.2 Technical Challenges in Endless Rolling

In order to realize endless rolling with minimum variations in tension and strip thickness, it is particularly necessary that the joined ends of bars be threaded with the same stability as in the rolling of steady regions during batch rolling. Furthermore, strips produced by endless rolling must not show quality deterioration or a decrease in yield. The technical challenges from these perspectives in endless rolling are presented below.

The first challenge is to join the sections of sheet bars 20 to 40 mm in thickness and up to 1 900 mm in width in a short time. In hot rolling, a temperature drop in the bar is not allowed in almost all cases in order to obtain the desired material property and the time allowed for joining bars on the entry side of a finishing mill is only a few dozen seconds. In addition, it is necessary to ensure joining strenght high enough to prevent breaks during finish rolling while tension is applied.

The second challenge is to supply the bars to be joined to the joining equipment without delay to the entry side of the finishing mill. It is necessary to perform high-accuracy rolling pitch control during the rolling on the roughing mill, and the process of joining must be controlled so that the succeeding bar can catch up precisely with the preceding bar.

The third challenge is to establish a high-precision flying gauge changing technique that ensures minimization of off-gauge lengths in high-speed finish rolling and minimum tension variations so that the joined part is not broken. It is also necessary to establish a technique for making crowns suitable for the target of each bar in continuous rolling, and a shape control technique so that the strip shape is not disturbed.

The fourth challenge is to develop a technique for instantaneously cutting strips that are continuously supplied from finish rolling while simultaneously coiling the strips one after another by the switchover of multiple coilers.

Since all of the above challenges exceed the capabilities of conventional rolling technology, it is necessary to develop innovative technology.

4 General Layout and Equipment Specifications

4.1 Equipment Makeup of the No. 3 Hot Strip Mill for Endless Rolling

Figure 2 shows the rolling equipment of the No. 3 hot strip mill and principal techniques necessary for endless rolling.

A series of equipment for joining sheet bars is installed from the delivery side of the mill R3. The sheet bar coiler that provides the starting point of joining has a buffer function for absorbing the time intervals between bars during the rolling on the roughing mill and plays an important role in continuously supplying sheet bars in endless rolling. A crop shear is installed between the sheet bar coiler and the sheet bar joining machine. This crop shear crops the tail end of the preceding bar and the head end of the successive bar so that these ends come into uniform contact with each other in the transverse direction. The sheet bar joining device is a traveling carriage type and completes sheet bar joining at a 20 m traveling stroke. A table capable of lowering and lifting, which is installed in the traveling range of the bar joining machine, permits flying joining without using a looper. A deburring machine at the exit side of the bar joining machine removes the raised area formed by upsetting.

The down coiler equipment is provided with a strip shear to cut the strip, which is continuously supplied to the coiler, at high speeds, and a high-speed coiler that coils the head and tail ends at high speeds by instantaneous switchover from the strip shear.

The basic specifications of each device are shown in **Table 1**.

4.2 Bar Joining Machine

Photo 1 shows the appearance of the bar joining machine, which is the central equipment of endless rolling. In addition to the travel drive mechanism, the interior of the carriage of the bar joining machine is provided with induction heaters which heat the end surfaces to be joined, clamps which secure the transfer bars, and an upsetter which joins the bars after clamping.

The induction heaters, which were developed for joining sheet bars in this mill, can heat joint faces of

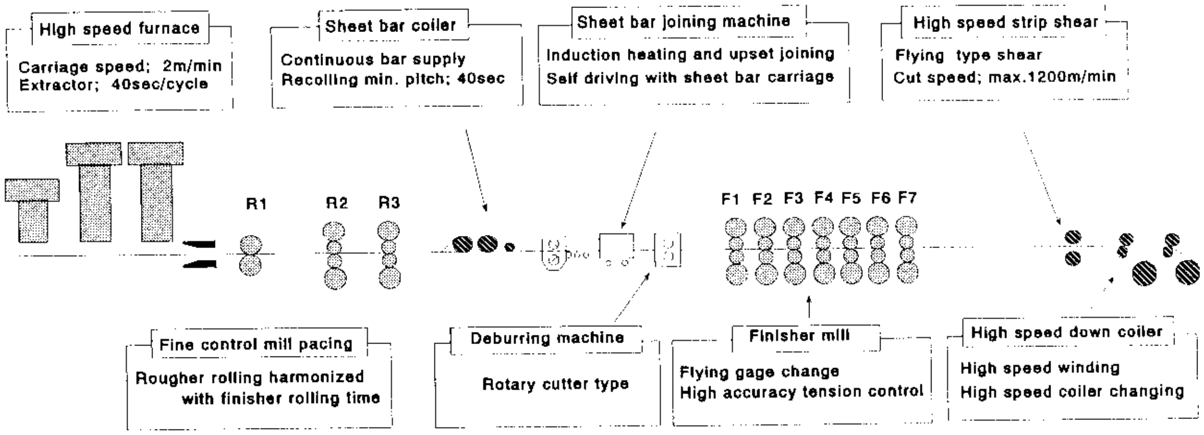

Fig. 2 Endless hot strip rolling equipments and key technologies

Table 1 Main specifications of endless hot strip rolling equipments

	Items	Specification
Endless rolling	Bar thickness (mm)	20 ~ 40
	Bar width (mm)	800 ~ 1 900
	Min. pitch (s)	45
Sheet bar coiler	Number of peelers	2
	Coiling speed (m/min)	Max. 340
	Recoiling speed (m/min)	Max. 150
Bar joining machine	Type	Self driving with sheet bar carriage
	Driving speed (m/min)	Max. 60
	Heating	Induction heater
Deburring machine	Type	Rotary cutter
Strip shear	Shearing speed (m/min)	1 200
	Shearing thickness (mm)	0.8 ~ 6.0

Photo 1 Sheet bar joining machine

bars 20 to 40 mm in thickness and 800 to 1 900 mm in width, to the joining temperature in a short time of 3 to 5 s. These are high-performance induction heaters.

The clamps and upsetter are high-rigidity mechanical devices for accomplishing upsetting which is uniform in the transverse direction, and hydraulic servo units are used in the control systems of these devices to perform high-accuracy position and pressure control.

The deburring machine on the exit side of the bar joining machine was recently developed for this mill to remove the burrs of hot steel. Cutting tools that work by hydraulic pushdown remove the burrs of sheet bars being transferred from the top and bottom surfaces and across the entire width at the same time.

5 Joining Technology

5.1 Joining Process

The sheet bar joining process is illustrated in **Fig. 3**. Two sheet bars are clamped with a slight gap produced between the tail end of the preceding bar and the head end of the succeeding bar (a) and induction heating of the joint faces is then performed (b). After the completion of heating, joining is conducted by upsetting (c). After the completion of joining, the clamps of the bar joining machine are opened and the joined sheet bars proceed to the finishing mill. At the same time, the bar joining machine returns to the start position for the next joining operation. Upsetting creates a raised area at the joint between the two bars (d). This portion is removed by the deburring machine at the exit side of the bar joining machine (e). The above sequence of operations (a) to (e) is repeated in endless rolling.

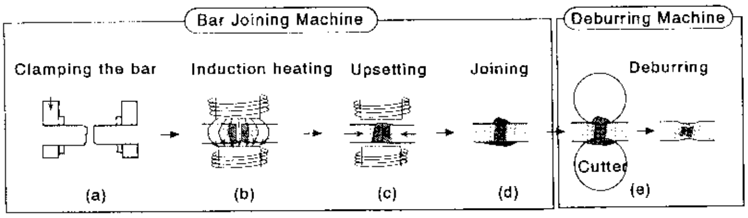

Fig. 3 Outline of the sheet bar joining process (cross section)

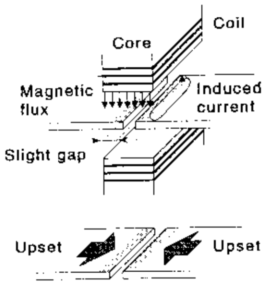

Fig. 4 Outline of joining process

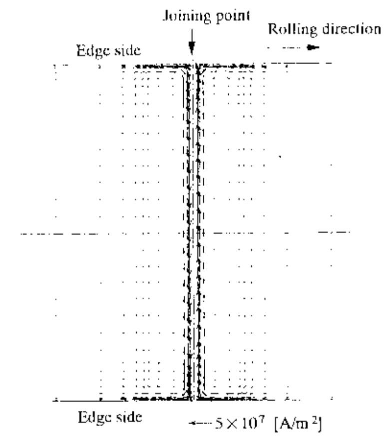

Fig. 5 Distribution of current density on sheet bar surface calculated by FEM (material size 30 t × 1 000 wmm)

5.2 Joining Technology

Although there are many challenges in the development of endless rolling, the challenge that involves the greatest technical difficulty is the joining of hot steel. A large number of methods for joining sheet bars have been proposed including the pack rolling-upsetting method[4], butt upsetting method[5], thermit welding method[6], laser welding method[7], mechanical joining method using a jigsaw[8], joining method by reducing flame treatment[9], induction-heating joining method[10], and joining method by direct electric energizing[11].

After considering these various joining methods, the induction heating method was adopted at the Chiba Works based on the results obtained from prior joining experiments and the fact that induction heating is used to join ERW pipes and tubes. At the same time the development of a new joining technique was tackled in order to join the sections of sheet bars with the same strength as that of the mother material.

The principle of induction heating adopted in the No. 3 hot strip mill is shown in **Fig. 4**. Two transfer bars are set with a slight gap between the tail end of the preceding bar and the head end of the succeeding bar. As shown in the figure, an alternating electromagnetic field generates an induced current concentrated on the end faces of the bars in such a direction that the induced current offsets the magnetic flux of the induction heater. The end faces of the bars are heated by the Joule heat generated by this induced current, causing their temperature to rise. **Figure 5** shows an example of the distribution of current density calculated by a three-dimensional electromagentic field analysis by the finite element method. It is apparent that the current is concentrated on the end faces of bars and that this current is uniformly distributed along the width direction of the strip.

Important challenges in the application of the principle of induction heating to the joining process include the determination of the inductor capacity, optimization of the dimensions of iron inductor cores, grasping the relationship between coil current and voltage and the rate of joint heating, and the conditions required for heating uniformity in the width direction of the strip.

The heating rate characteristics obtained in a heating test with actual equipment are shown in **Fig. 6**. In this figure, the heating rate ratio at various points of strip width are plotted against the maximum heating rate. A uniform temperature rise in the width direction was observed, indicating that joining is possible across almost the full width of the strip.

Photo 2 shows the microstructure of a cross section of sheet bars joined by heating. A perfect joint that has almost the same structure as the mother material was obtained. Oxide scale and inclusions such as sulfur, which are believed to affect joining strength, were not observed. Tensile test pieces were taken from the section after joining and the joint strength at room temperature was examined. The results of the test are shown in **Fig. 7**. The joint has almost the same strength as the mother material; this demonstrates that ideal joining was

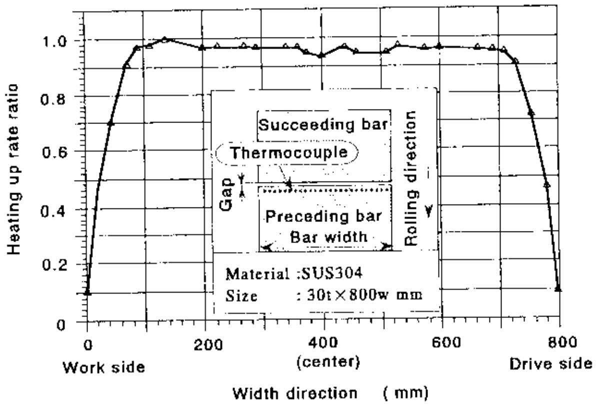

Fig. 6 Distribution of heating up rate ratio at joint between sheet bars

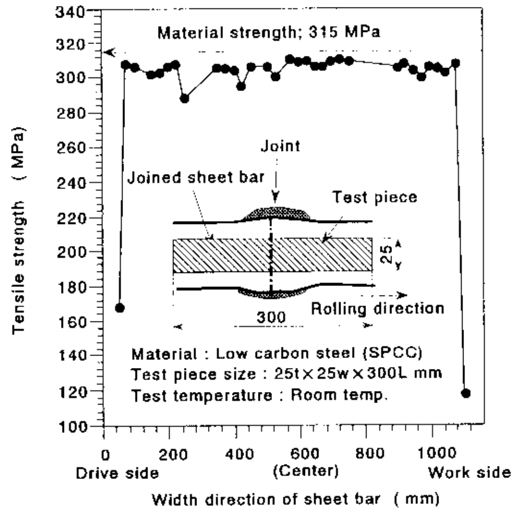

Fig. 7 Tensile strength distribution of joint

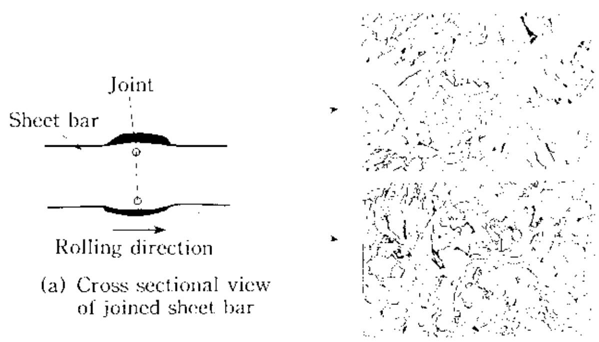

Photo 2 Cross sectional view of joined sheet bars

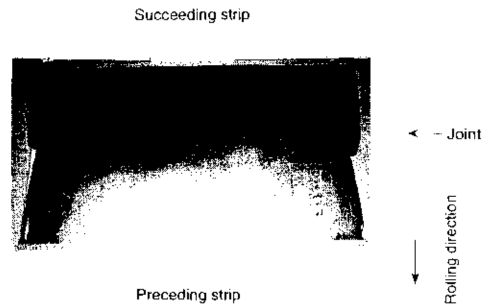

Photo 3 Joint in finish-rolled strip after deburring (strip size; 1 200 w × 1.2 tmn)

accomplished.

5.3 Deburring Technlogy

If a joint with a raised area is rolled as it is, the raised area is pushed in and an overlap defect will occur. This also damages the rolls of the finishing mill. To prevent this, Kawasaki Steel developed a method of removing the raised areas on the top and bottom surfaces simultaneously across the full width of the strip using a rotary cutter provided with special bits.

Photo 3 shows a joint of strip finish-rolled after deburring. The raised areas were completely removed and there was no defect at all after rolling.

6 Results of Endless Rolling

6.1 Improvement in Quality

The results of the endless rolling of hot strips are described below.

The strip thickness of an endless-rolled product from 10 joined sheet bars is shown in **Fig. 8**. Flying gauge changes were made at the joints between the first and second bars and between the ninth and tenth bars. The changes in thickness before and after the flying gauge changes, and before and after the joining of the materials of the same thickness, are very small. The thickness deviation in the portions corresponding to the unstable regions of a batch-rolled strip is $\pm 25\,\mu m$ and under.

Figure 9 shows changes in the strip crown at points 25 mm from the edges in the endless rolling of a strip from 10 jointed bars. Although the strip crown decreased gradually due to the thermal expansion of rolls, the occurrence of concave crowns and irregular shapes was not observed.

Figure 10 shows a comparison between the shapes of endless-rolled and batch-rolled strips at the delivery side of the finishing mill. Although waviness of about 3.0% occurred at the head end of the batch-rolled strip, no waviness at all was found in the endless-rolled strip. An excellent product was therefore obtained.

One of the important challenges in the manufacturing of products by endless rolling is the prevention of the roughening of the roll surface and ensuring the surface quality of strips. As a result of repetitive rolling of

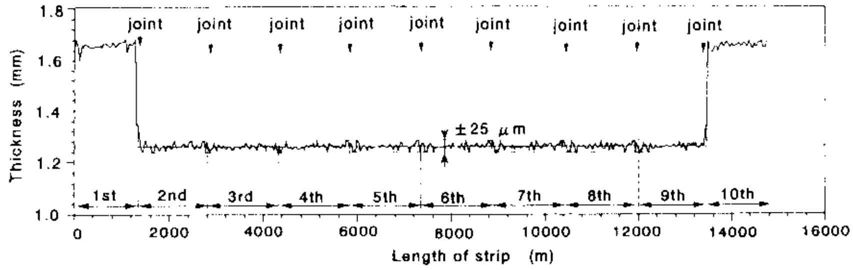

Fig. 8 Strip thickness chart of endless hot strip rolling measured by X-ray thickness meter at F7 delivery side (strip thickness; 1.66 → 1.26 → · · · → 1.26 → 1.66 mm)

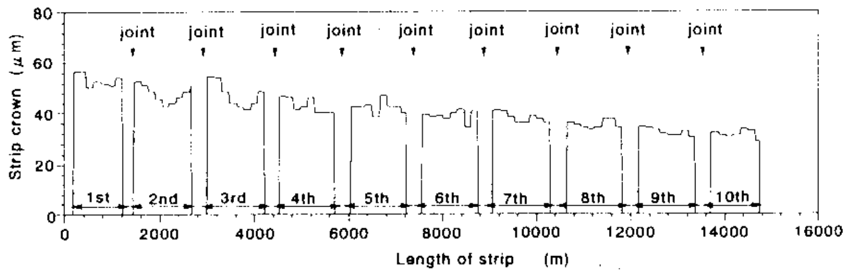

Fig. 9 Changes in strip crown during endless hot strip rolling measured by crown meter at F7 delivery side (strip thickness; 1.66 → 1.26 → · · · → 1.26 → 1.66, width; 1 220 mm)

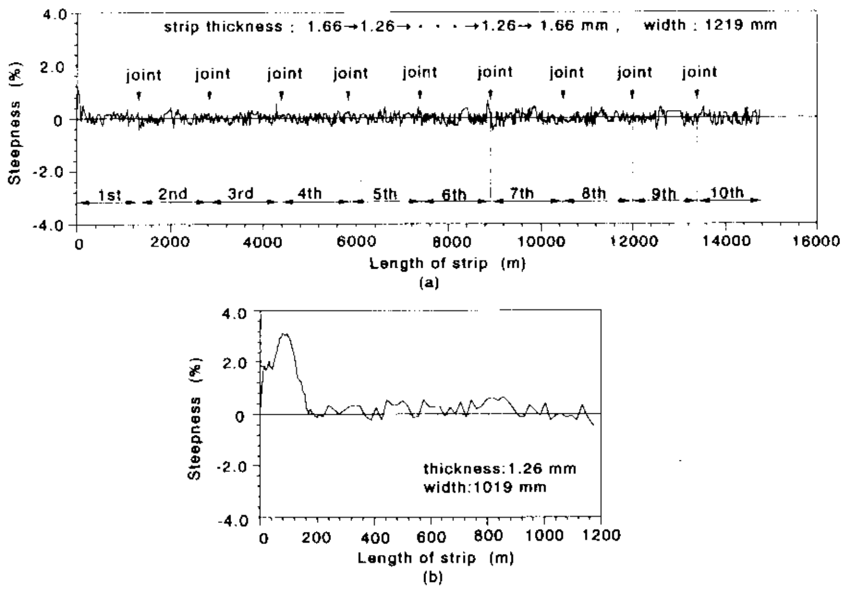

Fig. 10 Steepness chart at F7 delivery side (a) endless hot strip rolling (b) batch rolling

joined sheet bars, coarsening of the roll surface did not occur, nor were nonconforming products produced in terms of the surface quality of strips.

It might be said that overall, endless rolling is very stable owing to the effect of constant application of tension, which is the initial objective.

6.2 Effects Obtained in Production

Mostly thin-gauge products of less than 1.8 mm are produced by endless rolling. The effects of endless rolling are summarized in **Table 2**.

The greatest effect of endless rolling is a roughly 20%

Table 2 Benefits of endless hot strip rolling

Items	Effects	
Quality	Extremely slight changes of thickness over the entire length of the material	± 30 μ on gauge ratio 96% → 99.5%
	Extremely slight changes of width over the entire length of the material	Width margin 6 mm → 3 mm
	Little fluctuation of the coiling temperature over the entire length of the material	± 30℃ → ± 15℃
Productivity	Increase of productivity	20% increase
	Elimination of need for time to make unexpected roll changes due to pinchers	90% decrease
Yield	Drastic reduction of shape rejects at the top end and tail end	80% decrease
	Drastic reduction of surface defects due to pincher marks	90% decrease

increase in productivity, resulting, to a considerable extent, from an increase in the rolling speed and the elimination of the dead time between sheet bars. Furthermore, yield improves greatly because of a decrease in rejects at the head end for dimensional and shape reasons.

Tail-end pinchers and the striking of the head end of the strip against the top guide, which impair productivity in the batch rolling process, did not occur at all in endless rolling. This eliminated the need to make unexpected roll changes due to pinchers. At the same time, grinding rolls containing pinchers has also become unnecessary, reducing roll consumption greatly.

In addition, it has become possible to produce strips exceeding the previous manufacturing capacity, which were not produced in the ordinary batch rolling, as new products of endless rolling. For example, it is now possible without the problems of pinchers, etc., to produce 1.2 mm thick strips in widths up to 1 600 mm and 1 200 mm wide strips in thicknesses of 1.0 mm minimum. For lubricated rolling as well, it has become possible to lubricate the full length of a strip as initially expected. Therefore, the effect of lubrication has substantially stabilized the process.

7 Conclusions

To stabilize the quality of the top and tail ends of the strip, improve threadability, manufacture thin-wide strips and ultra-thin strips, and to conduct lubricated rolling along the full length of the strip, Kawasaki Steel developed endless rolling technology by which sheet bars are joined on the entry side of the finishing mill. This was the first time in the world that continuous finish rolling in a hot strip mill had been achieved. This process started operation in the No. 3 hot strip mill at Kawasaki Steel's Chiba Works. An overview and results of this endless rolling are as follows:

(1) To carry out endless rolling, sheet bar coilers, a sheet bar joining machine, a deburring machine and a strip shear were installed.

(2) An induction heating upset method was developed which was able to join sheet bars in a very short time of about 5 s. Tests of joining using actual equipment have confirmed that the joint strength has the same values as those of the mother material. Furthermore, joint breakage does not occur in finish rolling.

(3) Gauge accuracy of ±25 mm was achieved along the full length of the strip owing to endless rolling. In addition, no irregular shapes occur and rolling is very stable.

(4) It has become possible to stably produce thin-wide strips 1.2 mm in thickness and 1 600 mm in width and ultra-thin strips 1.0 to 1.2 mm in thickness.

(Reprinted with permission of AISE)

References

1) Y. Ogawa, T. Nakamura, and N. Kitao: *Kawasaki Steel Technical Report*, **34**(1996), 5–10
2) ISIJ: Advanced Technology of Hot Strip Mill in Japan (1987), 143
3) S. Matsuoka, T. Obara, K. Tsunoyama, T. Sakai, Y. Saitou, and K. Katou: *CAMP-ISIJ*, (1986), 136
4) Nippon Steel Corp.: Jpn. Kokai 51-112458
5) Ishikawajima-Harima Heavy Industries Co., Ltd.: Jpn. Kokai 60-240305
6) Ishikawajima-Harima Heavy Industries Co., Ltd.: Jpn. Kokai 60-191681
7) Nippon Steel Corp.: Jpn Kokai 6-516875
8) Ishikawajima-Harima Heavy Industries Co., Ltd.: Jpn. Kokai 60-148685
9) Sumitomo Metal Industries, Ltd.: Jpn. Kokai 4-200907
10) Hitachi, Ltd.: Jpn. Kokai 60-244401
11) Kawasaki Steel Corp.: Jpn. Kokai 61-159285