A NEW ON-LINE BAR JOINING TECHNOLOGY FOR ENDLESS HOT ROLLING

by Jong-Sub Lee[1], Ki-Chol Kim[1], Chun-Soo Won[2], Kenji Horii[3] and Takao Funamoto[3]

[1]Steel Process & Automation Research Team, RIST
#32 Hyoja-dong, Nam-gu, Pohang, 790-330, Korea, jonglee@rist.re.kr
[2]Hot Rolling Technology Team, POSCO
#1 Goedong-dong, Nam-gu, Pohang, 790-785, Korea, wonan@posco.co.kr
[3]Technical Development Group, Mitsubishi-Hitachi Metals Machinery, Inc.,
1-1 Saiwai-cho 3-chome, Hitachi, 317-8511, Japan, kenji_horii@M-Hmm.co.jp

ABSTRACT

A new on-line bar joining technology employing the concept of a solid-state joining has been developed for the endless rolling by POSCO, RIST and MHMM Inc.. In the process, the bars are partially descaled, partially overlapped, joined by shearing action and crops are finally removed. The feasibility of the developed process was evaluated in this study in terms of microstructures and mechanical properties of joints, and the response of the joint to rolling.

KEYWORD

Endless rolling, bar joining technology, shearing, solid-state joining, joint efficiency

1. Introduction

The concept of the endless hot rolling was introduced to meet demands for diverse products of hot rolled steel sheets and a cost-effective process compared to the conventional batch-type process. The tail end of a preceding bar and the top end of a following bar are joined together after rough rolling and the joined bars are finish-rolled continuously in the endless rolling process. The process can be characterized by continuous rolling without idle time, constant rolling speed and no crop to discard. It has potentials to provide the large-scale steel works with the following advantages:

Expansion of product lineup: Production of thinner, wider and harder steel sheets; Stable rolling of thin and hard-to-roll materials.

A. Increase in productivity: Great reduction in mill idle time, and constant rolling speed with reduction of mill acceleration and deceleration time.
B. Improvement of product quality: Improvement in accuracy and uniformity of strip thickness, crown, and width.
C. Energy savings: Reduction of the mill acceleration and deceleration frequencies.
D. Increase of yield: Minimization of miss rolling of thin and hard-to-roll materials; Application of tension at top and tail parts of bar.

To perform the endless hot rolling in a hot strip mill, several new technologies have to be developed including a coil box, bar joining, and high speed shearing. Among them, the bar joining is the key technology for the endless rolling and has to be first developed.

Kawasaki Steel's Chiba Works has employed induction welding as the bar joining process since March 1996 [1], and Nippon Steel's Oita Works has employed a high power laser welding since April 1998 for endless hot rolling [2]. The induction welding requires the ends of the bars to be heated and then, the heated area is upset for joining. Laser welding requires precise cutting to get sound welds.

Compared to the joining processes mentioned above, a new joining method with an innovative principle to achieve the shortest joining time of less than one second has been recently developed by POSCO and Hitachi, Ltd.. This joining process employs a unique concept of solid-state joining that utilizes the crop-shearing action, and consists of the following steps. First, traveling speeds of preceding bars and following bars are synchronized on the roller table. Then, top end of the following bar is placed on top of the tail end of the preceding bar immediately after removing scale. Upper and lower knives shear the overlapped area, which creates scale-free new surfaces from the both bars. The scale-free surfaces are simultaneously joined together by the partial force (upsetting force) normal to the interface.

The newly developed process employs a stationary joining equipment while the joining equipment in the other processes has to move. The stationary joining equipment can significantly reduce line-space. This process is also simple, cost-effective and easy to maintain.

This paper describes the bar joining process that is the key technology for the endless rolling, specifically, the mechanism of bar joining, the pilot plant equipped with the joining machine and hot rolling mill, and performance test results including the joint strength, microstructure of the joints and response of the joints to hot rolling.

2. Sheet Bar Joining

2-1. Layout of the Endless Rolling Line

Fig. 1 shows the layout for the endless rolling mill that employs a pendulum type-joining machine. For the endless rolling, coil boxes and joining machine have to be installed between RM and FM. The joining machine and equipment such as descaling and crop disposal equipment related to the joining process locates between the coil boxes and FM.

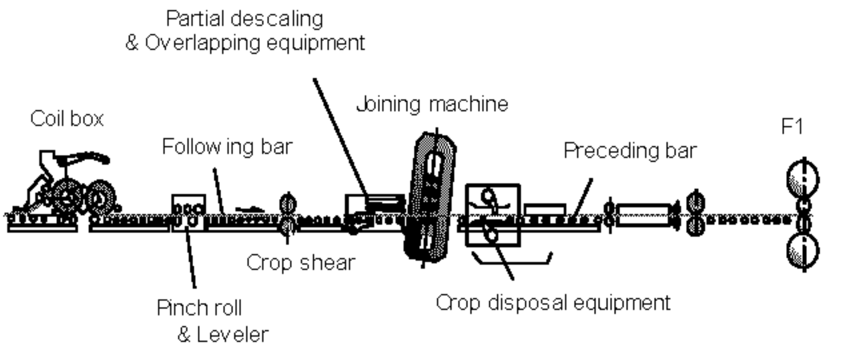


Fig. 1 Layout of endless rolling mill

2-2 Joining process and mechanism

Fig. 2 illustrates the bar joining procedure. The procedure consists of four steps: partial descaling, overlapping, joining, and crop disposal.

1. Partial descaling by high-pressure water is first performed on the area to be joined before overlapping.
2. The top end of the following bar is partially overlapped on the tail end of the preceding bar by increasing the traveling speed of the following bar.
3. Both bars are joined by shearing action of the stationary pendulum type-joining machine.
4. Crops on both sides are pushed off from the joint and disposed.

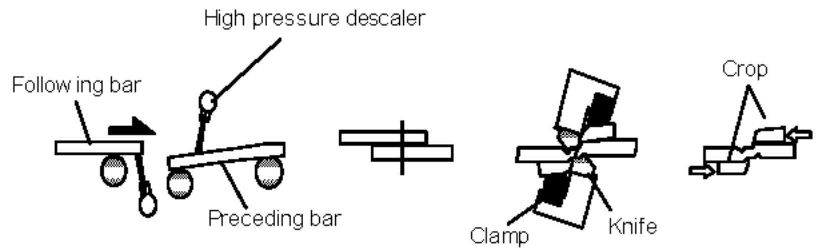
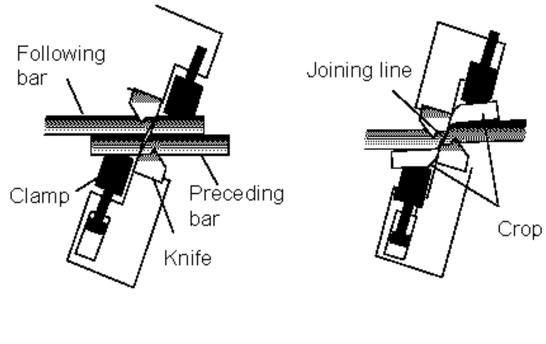


Fig. 2 Joining procedure consisted of four steps: partial descaling, overlapping, joining and crop disposal

The joining action is shown in Fig. 3 in detail. The knife consists of an edge for shearing and a wedge for preventing sliding (metal flow) by biting the bar. The edge similar to that in a crop-shear knife, cut the overlapped bars. The wedge and clamp provide the force enough to join the bars by holding the bars tightly. Fig. 4 shows the shape of the specimen after joining. Since the stroke of the knives is slightly higher than the plate thickness, there is a step between front part and rear part of the specimen.

In this process, the shearing process creates scale-free surfaces and the newly formed surfaces are joined together. Joining force is the partial force originated from high shearing pressure. Since shearing plane is inclined as shown in Figs. 3 and 4, a partial force normal to the interface acts as joining force with friction between two newly formed surfaces. Friction between two newly formed surfaces assists joining by heating up the surfaces and accelerating diffusion. The process is usually performed at elevated temperatures, about 1,000°C.

However, partial descaling is still essential to get a sound joint since small amount of segments of broken scale can drag into the interface during the joining process and the scale along the interface degrades the joint properties. The joint properties can be improved remarkably with a decrease in the amount of scale along the interface. The partial descaling was performed by high-pressure water.



(a) Before shearing (b) After shearing

Fig. 3 Schematic of the joining process

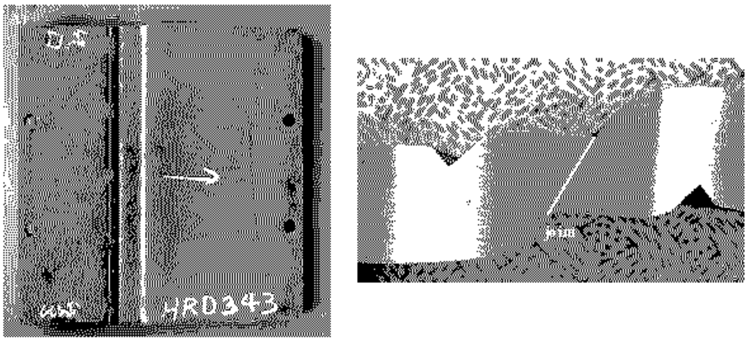


Fig. 4 Shape of the joint. A) Plane view, B) Cross-sectional view

2-3 Pilot plant joining equipment

Fig. 5 shows the detailed drawing of the pilot plant joining equipment. For joining test, the bars are reheated to 1200 ~ 1300°C in the furnace. After reheating, the two bars are exposed to air for 30 to 60 seconds to simulate scale formation between the RM and FM of an actual hot rolling mill. Then, the reheated bars are partially descaled by high-pressure water, overlapped, joined together and finally crops are removed. The joint is directly hot-rolled or hot-rolled after reheating.

Table 1 shows the specification of the pilot plant. When 28mm thick bars are joined, maximum width that can be joined in the plant is 450 mm for most carbon steel and 300 mm for austenitic stainless steel.

3. Microstructures and Mechanical Properties of the Joints

Fig. 6 shows macro- and micrograph of the interface. It is difficult to identify the interface macroscopically and microscopically except that some scales locally exist along the interface. The grains adjacent to the interface are merged into one grain, which indicates that both bars are soundly joined. The identification of the interface becomes more difficult after the joint is hot-rolled. Fracture surface of the joint after tensile test is shown in Fig 7. The fracture occurs along the interface but the surface exhibits dimples, which indicates a ductile fracture.

Fig. 8 shows joint strength distribution across width direction. Material used in the test was plain carbon steel, SS 400. The joint was cut into 30 mm wide segments for the test and the segments were directly tensile-tested. The tensile test was performed at room temperature. The tensile strength of the joints ranges from 250 to 290 MPa, which indicates joint efficiency (joint strength / base metal strength) is about 0.6 ~ 0.7. The joint efficiency at high temperature (950°C) was almost same as that at room temperature. WS (work side) and DS (drive side) edges exhibited lower tensile strength than the center part of the joint.

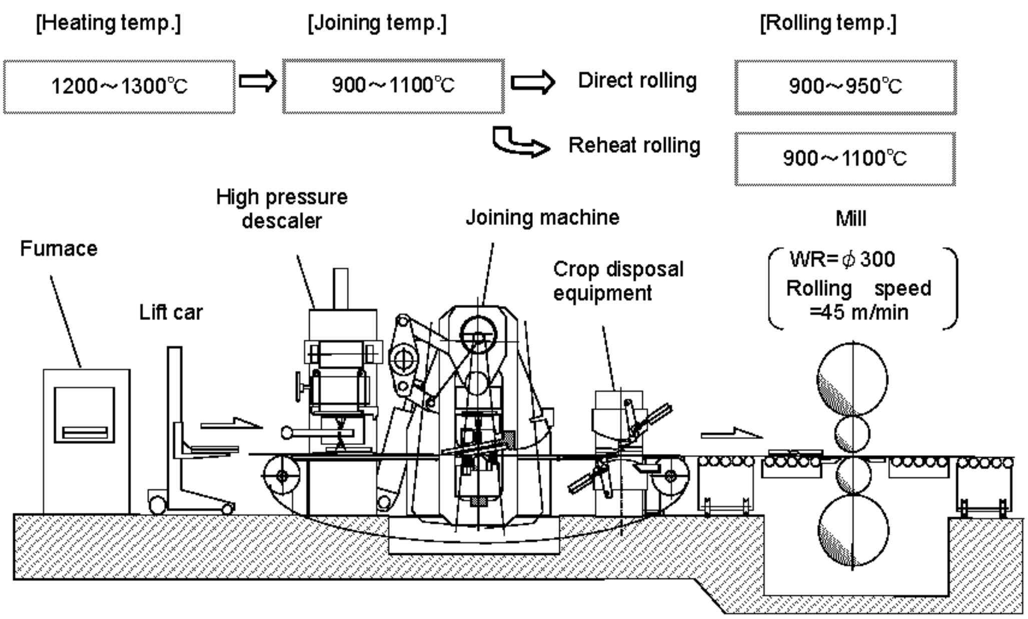


Fig. 5 Pilot plant joining equipment

Table 1 Specification of the pilot plant

Item	Specification
Material	SS400, STS 304 and Others
Bar thickness	28～36 mm
Bar width	Max. 450 mm
Partial descaling	High pressure water
Joining machine type	Pendulum
Joining time	<1 sec
Joining speed (Vertical)	Max. 150 mm/sec
Crop disposal	Hydraulic cylinder

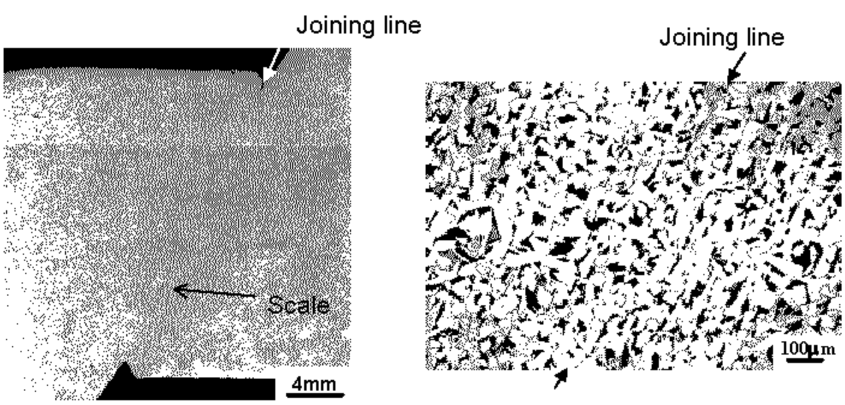


Fig. 6 Macro- and microstructures of the joints in SS 400 (bar thickness: 28mm, joining temp.: 1090°C)

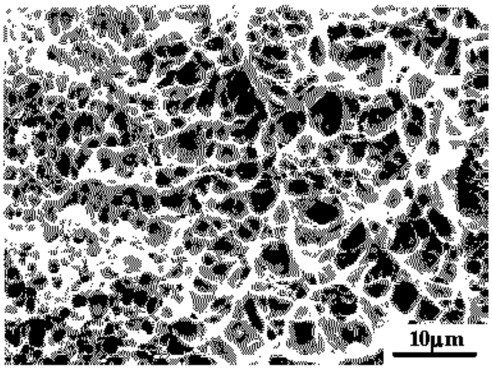


Fig. 7 SEM fractograph of a tensile-tested fracture surface. Tensile strength was 287 MPa and fracture occurred along the joint interface.

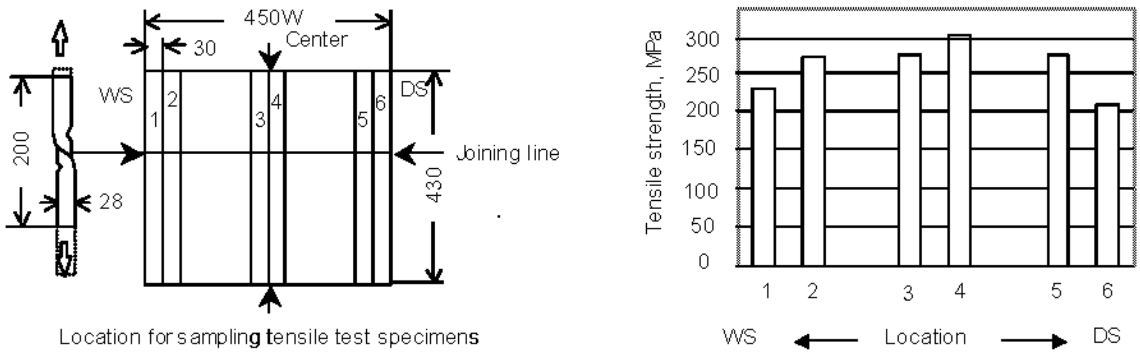


Fig. 8 Joint strength distribution in a width direction

4. Rolling behavior of the joint and line test results

A 28 mm thick bar was hot rolled to 6.7 mm thick sheet by four-pass rolling as shown in Fig. 9. Reduction ratio of each pass was 30%. After hot rolling, the edge-opening ratio that can be defined as (sheet width – length of soundly joined area at joint)/sheet width, was about 5%.

To simulate the response of the joint to bending force during finish rolling, high temperature bending test was performed. Fig. 10 shows equipment employed in the test and Fig. 11 compares the bending radius during the test with that of looper between stands. The critical radius in the test at which the joint started to open was much smaller than the radius experienced in the actual rolling, which indicates the joint will not be broken by the interstand looper.

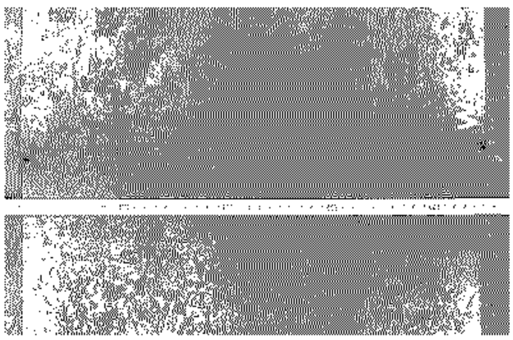


Fig. 9 Macrograph of the joint after four pass rolling. Both WS and DS edges were opened slightly after rolling and the ratio was about 5%.

Since the joint has to be sound enough not to be broken during the finish rolling, the response of the joint to hot rolling was investigated at actual rolling line. Two 450mm wide joints were welded in parallel and dummy bars were welded at the front and the back of the specimens, which made 840mm (W) x 9,000 mm (L) x 28mm (T) bar as shown in Fig. 12. The specimen was hot rolled from 28mm to about 5mm. Edge opening ratio after hot rolling was about 13%. Table 2 shows tensile properties after hot rolling. As indicated in the table, yield strength and tensile strength of the joint was almost same as those of the base metal though elongation is lower than the base metal. The fracture initiated at the joint but propagated through the base metal.

Fig. 13 shows microstructures along the interface. Cracks (regions not metallurgically joined) along the interface were observed at top and bottom side in thickness direction but it was impossible to identify the interface in most area except top and bottom.

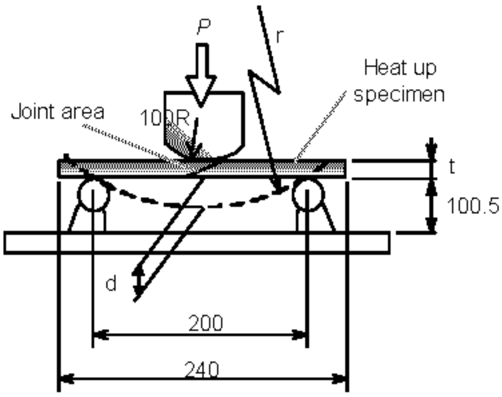


Fig. 10 Schematic of the bending test

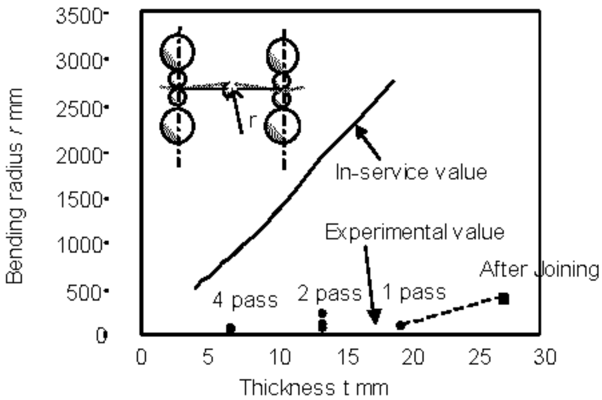


Fig. 11 Bending test result comparing in-service value and experimental value

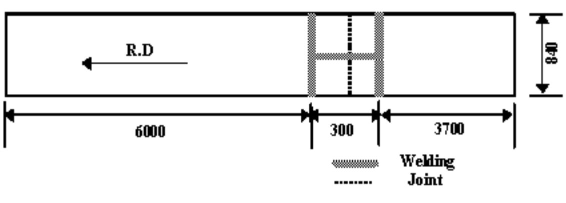


Fig. 12 Configuration of test plate for line test

Table 2. Tensile properties of hot rolled joint

#	Thick. (mm)	Width (mm)	Y.S. (MPa)	T.S. (MPa)	El. (%)	Location*
1	6.50	25.04	421	519	18.5	B.M.
2	6.56	25.05	403	492	14.8	Joint+B.M

* Location where fracture initiated and propagated

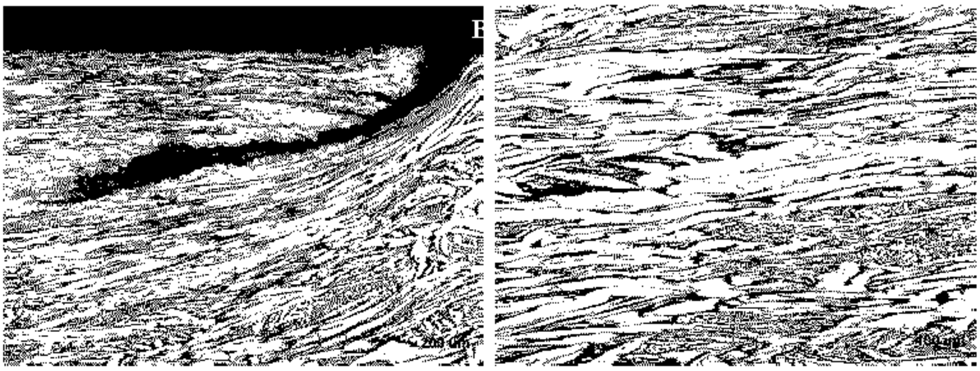


Fig. 13 Microstructures along interface. A) Top, B) Center

5. Summary

Bar joining technology is the most important and has to be developed for the application of the endless hot rolling process. A new solid-state joining technology using shearing action has been developed and the feasibility of the technology was evaluated in this study. The pilot plant equipment that can join maximum 450 mm wide bars, was used in this study.

Joint tensile strength ranges from 60% to 70% of the base material. In the line test, the joint can be hot rolled without failure and the edge-opening ratio can be controlled to less than 15% of the width. Joint strength after finish rolling was almost same as the base material strength. From these results, it can be concluded that the developed technology can be used as a bar joining process for the endless rolling since the joint withstand and even out-perform strip tension requirements for tandem rolling.

References

1. T. Takano, K. Matsuda, S. Moriya, N. Shibatomi, Y. Mito and K. Hayashi: "Endless hot strip rolling at Kawasaki Steel Chiba Works, Iron and Steel Engineer, February 1997, 41 – 47

2. S. Matsuo, K. Maeda, S. Osita, E. Kuboyama, S. Nishibayashi, Y. Mitai, K. Arasawa, H. Nishida and H. Akasaki: "Outline of Continuous Finish-Rolling at Oita Works", CAMP-ISIJ, Vol.13, 2000