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No. 3 hot strip mill in Chiba Works of Kawasaki Steel started its operation in May 1995. The mill meets the strict quality requirements of customers in recent years and expands the product size of stainless steel. The dimensional and surface quality of stainless steel at No. 3 hot strip mill further advanced by introducing highly accurate and high-response thickness gauge control, set-up and dynamic control for optimizing crown and flatness at pair cross mill, equipped with on-line roll grinder, and edge-seam control. (1) Product size of hard steel strips such as stainless steel has been expanded and high accuracy in longitudinal thickness has been achieved over the full length of hot rolled strips. (2) Low crown of stainless steel has been able to be obtained by developing highly accurate crown and flatness control. (3) Reduction of the edge-seam defects of stainless steel has been developed by using the sizing press.

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Hot Rolling Technology for Producing High Quality Stainless Steel at No. 3 Hot Strip Mill in Chiba Works*

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1 Introduction

No. 3 hot strip mill at Chiba Works of Kawasaki Steel (Chiba 3HOT) has operated smoothly since it was started up in May 1995.[1,2] The mill was constructed as a rolling mill which is capable of responding to the stricter quality requirements of customers and the demand for a wider range of product sizes,[3,4] and will have a high level of competitiveness in the 21st century.

Production at Chiba 3HOT centers on ultra-thin hot strip and high grade steel strip. Among these, stainless steel accounts for approximately 10% of total production, and thus is one of the main products of the mill. In comparison with carbon steel, stainless steel is a hard-to-roll material, being characterized by high deformation resistance at elevated temperatures and strict surface quality requirements.[5] At Chiba 3HOT, state-of-the-art hardware and software were introduced,[6] considering rolling of hard-to-roll materials, and dramatic improvements have been achieved in longitudinal thickness, width, and crown dimensional accuracy.

This report describes the control technologies for the dimensional and surface quality of hot rolled stainless strip manufactured at Chiba 3HOT, including thickness, crown, and flatness, and the high quality levels achieved.

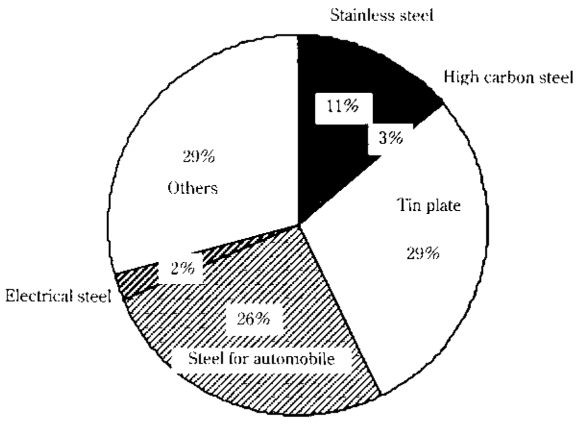

Fig. 1 Product mix at Chiba Works No. 3 hot strip mill

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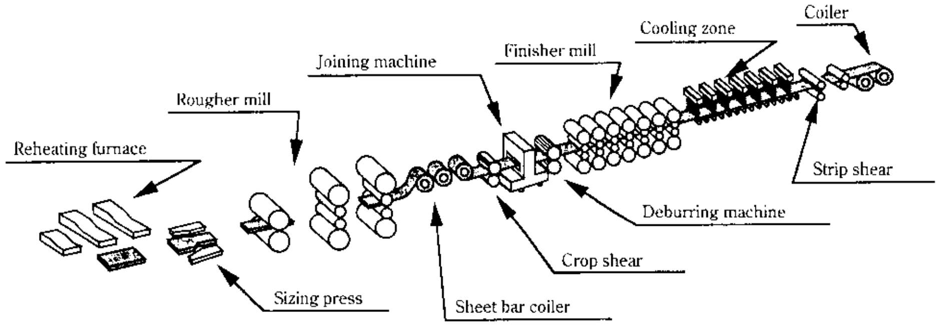

Fig. 2 Layout of No. 3 hot strip mill

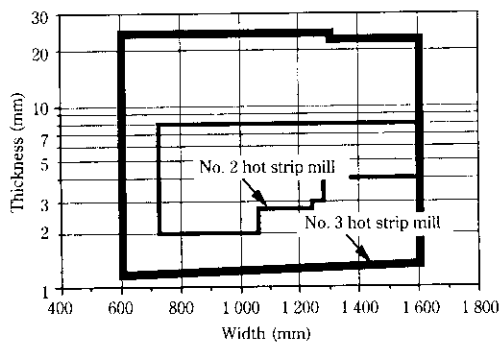

Fig. 3 Available size range of No. 3 hot strip mill (SUS304)

2 Outline of Chiba Works No. 3 Hot Strip Mill

Figure 1 shows the product mix at Chiba 3HOT. As a distinctive feature of this mill, Chiba 3HOT produces a variety of types of high grade steel, including stainless steel, high carbon steel, tin plate, steel for automobiles, electrical steel, and others. Strict quality requirements are applied to these products at all time in terms of surface quality, dimensional accuracy, and material properties.

Figure 2 shows a schematic drawing of the layout of the equipment at Chiba 3HOT. The equipment comprises three reheating furnaces, a sizing press, three rougher mills, a sheet bar coiler, joining machine, seven finisher mills, a cooling zone, strip shear, and two coilers. As features of this equipment in the rolling of stainless steel strip, (1) the available size range for rolling has been expanded by adopting high rigidity, heavy reduction mills in the finisher mill, (2) thickness accuracy has been greatly improved by adopting high-speed hydraulic screwdown in all stands of the finisher mill, (3) stable crown and flatness accuracy have been achieved while also realizing chance free rolling with other types of steel by adopting pair cross mills in the finisher mill, and (4) a technology for reducing edge-seam defects was developed by practical application of the sizing press.

Figure 3 shows the available size range of SUS304. The adoption of high rigidity finisher mills with a maximum load capacity of 5 000 t has greatly expanded the range of thinner products which can be produced.

3 Product Technology for High Quality Products

3.1 Thickness Control

High accuracy thickness control has been realized by introducing high-speed hydraulic screwdown and high-response AC mill motors at all stands of the finisher mill, and X-ray thickness meters which are installed at the delivery side of F4-F7 stands. **Figure 4** shows the configuration of the gauge control system. The gauge control system comprises (1) set-up control, which decides the roll gap by estimating the rolling force from the deformation resistance of each steel type before rolling, (2) automatic gauge control (absolute gauge AGC: AG-AGC), by an absolute value gauge meter method for obtaining the thickness accuracy at the leading end, and dynamic set-up (DSU), which determines the screwdown position based on the actual results of the X-ray thickness meters between the stands, and (3) mill modulus control (MMC) for responding to gauge fluctuations within one bar and monitor AGC (M-AGC) using X-ray thickness meters. Using these types of control, it is possible to realize high thickness accuraccy even with stainless steel, which is characterized by a high rolling force. As one example, **Fig. 5** shows the changes in the strip thickness in the longitudinal direction of a coil of SUS304 with a thickness of $2.0 \times 1\,050$ mm. High thickness accuracy of $\pm 25\,\mu$m has been achieved over the full length of the coil.

3.2 Crown and Flatness Control

The factors which determine the dimensional accuracy of hot coils are the strip thickness, strip width, and strip crown. However, particularly in the case of stainless steel strip, a low crown strip with a cross-sectional profile approaching perfect rectangularity (dead flat) is required.

Kawasaki Steel was among the frist makers to develop

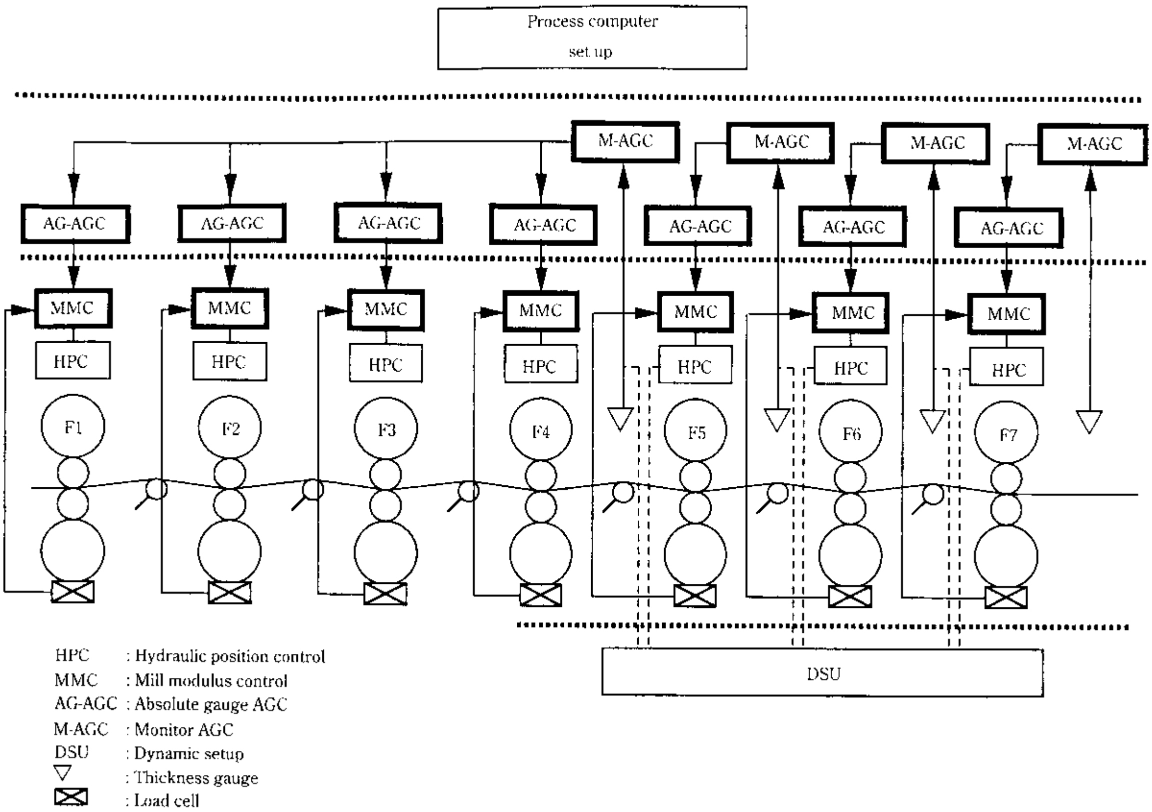

Fig. 4 Outline of automatic gauge control system in No. 3 hot finishing mill

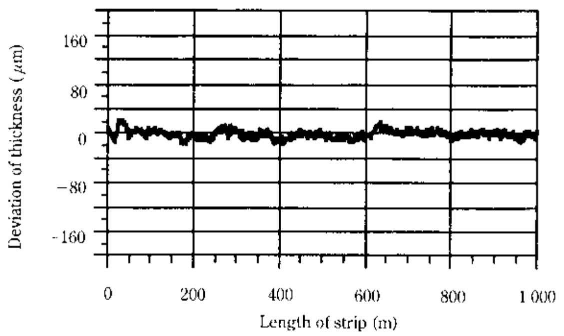

Fig. 5 Strip thickness chart measured by X-ray thickness meter at F7 delivery side (SUS304; 2.0 mm × 1 050 mm)

and introduce crown control mills. Beginning with the introduction of the K-WRS (Kawasaki Steel work roll shifting mill)[7], which was a 4-high work roll shift mill, at Chiba Works No. 1 hot finishing mill in June 1983, the company then introduced the 6-high HC mill (high crown control mill)[8] at the Mizushima Works hot finishing mill in September 1983, followed by a crown control mill[9,10] which combined the K-WRS with a strong work roll bender at Chiba Works No. 2 hot finishing mill in April 1986. As a result, it became possible to reduce the crown of stainless steel strip to less than 1/3 of the conventional amount.[5] At Chiba 3HOT, pair cross mills, which have an even higher crown control capacity, were introduced for the purpose of building high quality into various types of high grade steel. This mill is a type in which the roll gap between the rolls in the axial direction is changed by mutually crossing the roll shafts. In addition, quality and accuracy have been improved by upgrading the sensor and control functions, and by developing a high accuracy crown and flatness prediction model for maintaining the desired strip profile and flatness stably at all times, and a logic for determining rolling conditions based on the model.

Figure 6 shows an outline of the crown and flatness control system. The control functions can be broadly divided into set-up control and dynamic control. The actuators which are the objects of contrrol are the cross angle and work roll bending force. It may also be noted that ORG (on-line roll grinder) are provided to control high spots and roll wear.

In set-up control, the cross angle and WR bending force are set automatically so as to obtain the target values of crown and roll wear. The cross angle and WR bending force are determined in accordance with the logic shown in **Fig. 7** so that it is possible to achieve the target values of the product crown and flatness while maintaining flatness stable at each stand.

However, errors occur in the prediction of the rolling

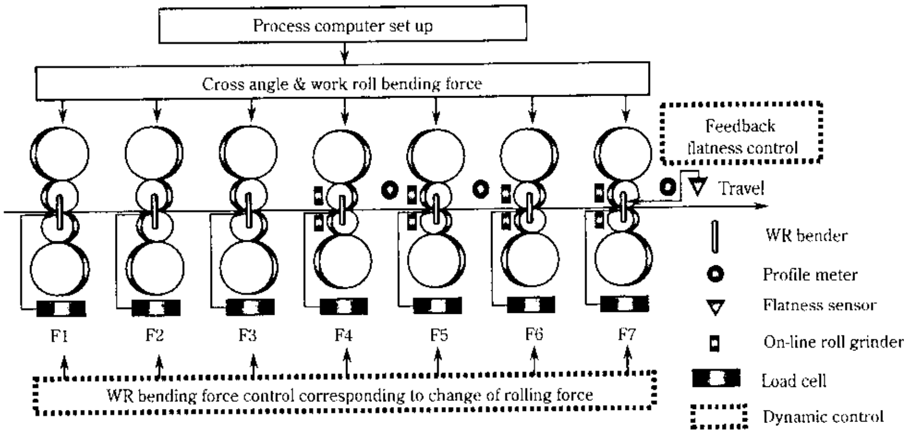

Fig. 6 Outline of crown and flatness control system

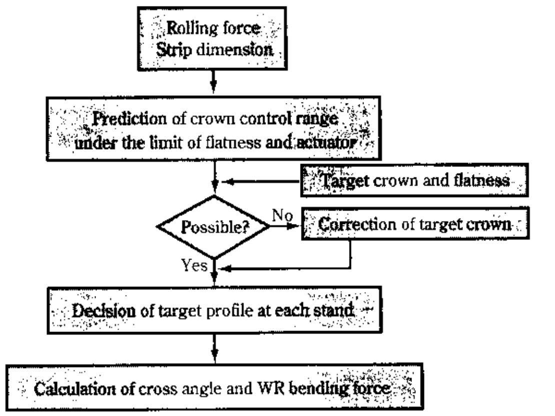

Fig. 7 Schematic diagram of crown correction plan

force and other factors in the above-mentioned set-up control, and the crown and flatness fluctuate due to changes in the rolling force over the length of the coil and the growth of thermal crown. Therefore, dynamic control is also applied in order to maintain the product crown flatness at the target values. In dynamic control, the WR bending force is changed in response to the rolling force, which is detected by load cells at each stand, flatness, which is detected by flatness meters at the delivery side of finisher mills, and changes in the thermal crown, which are calculated in real time.

Figure 8 shows an example of the trend in strip crown in the hot rolling schedule of SUS304. In this rolling schedule, the thickness varied from 2.3 to 7.0 mm and width waried from 800 to 1 260 mm, and the schedule

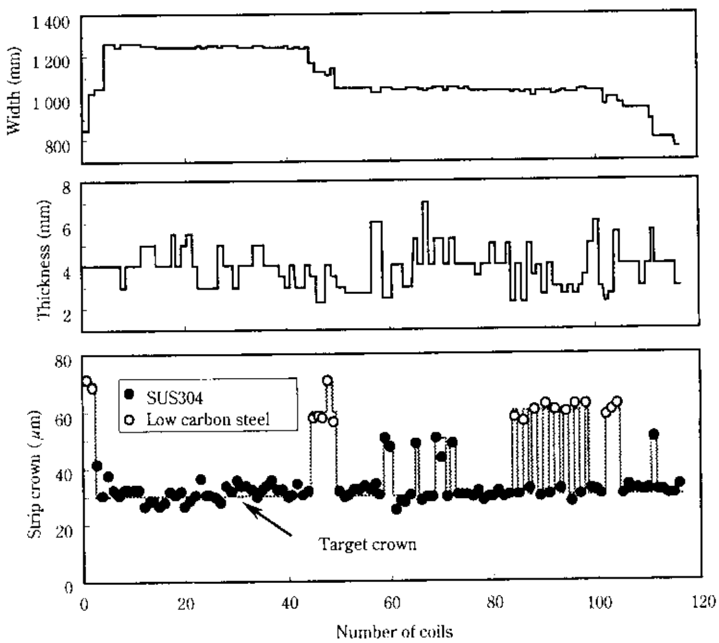

Fig. 8 Change of strip crown in hot rolling schedule

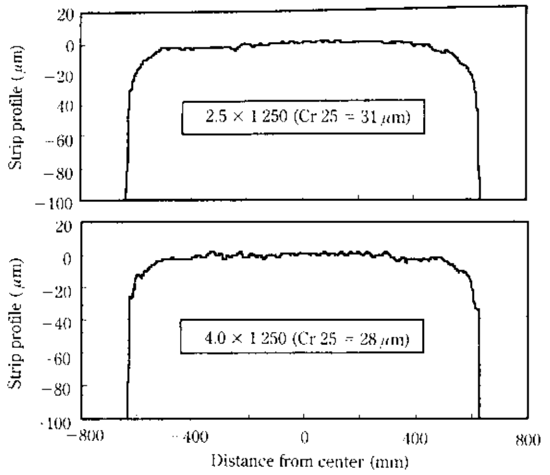

Fig. 9 Typical strip profiles of SUS304 steel

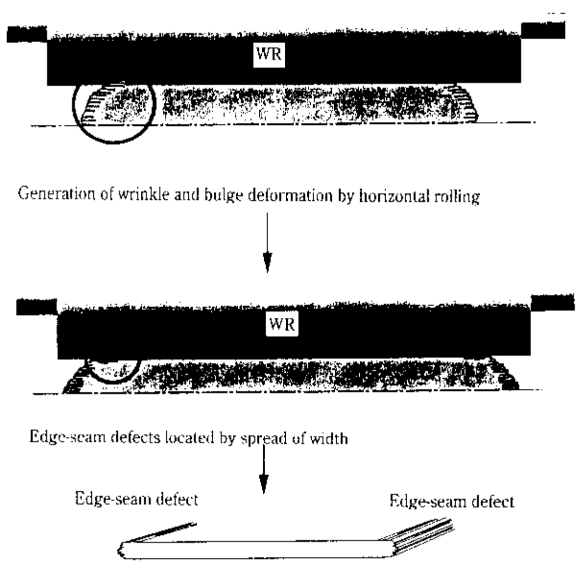

Fig. 10 Outline of generation of edge-seam defect

included mixed rolling with low carbon steel. Further, the target crowns with SUS304 were 30 μm and 50 μm, whereas those with the low carbon steel were 60 μm and 70 μm. It can be understood that a low crown of 30 μm was achieved with the SUS304, regardless of the width and thickness. Moreover, the crown was obtained as targeted even in mixed rolling with low carbon steel, which has a greatly different rolling force.

Figure 9 shows the strip profile of SUS304 with a target crown of 30 μm. As can be understood from the figure, it was possible to obtain a satisfactory profile with a small body crown.

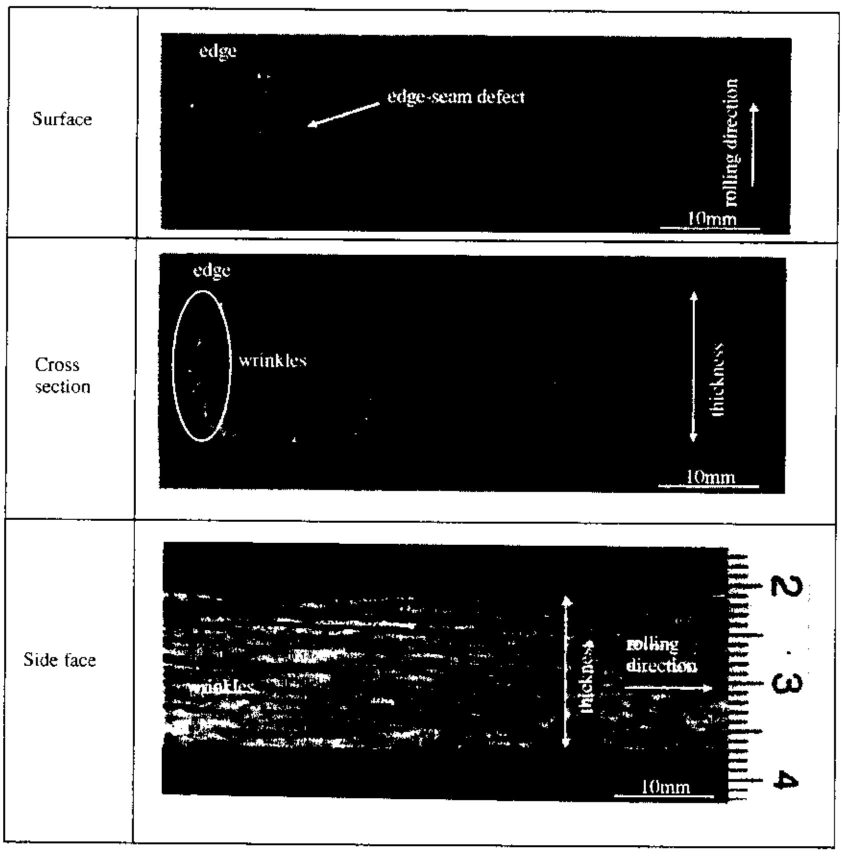

Photo 1 Proportion of edge-seam defects (SUS430)

3.3 Control of Edge-Seam Defect in Stainless Steel Strip

Generally, a linear defect called the edge-seam defect occurs parallel to the rolling direction at both edges of hot rolled stainless steel strips. With reduction in the width margin as a result of high accuracy profile control and high accuracy strip width control over the full length of coils, attention has been drawn to the edge-seam defect, which occurs at the edges of strips in conventional rolling without control. In addition, with stainless steel strip, which is subject to strict surface quality requirements, there is also a problem of reduced product yield, because edge trimming is unavoidable at parts with the edge seam defect after cold rolling. Thus, securing high quality in the strip edges has becomes an important task. The following describes the technology for preventing edge-seam defects which was developed at Chiba 3HOT.

3.3.1 Mechanism of edge-seam defect

The edge-seam defect occurs when wrinkles generated at the sides of the slab during horizontal rolling by the rougher mill are folded over onto the top and bottom surfaces of the steel strip in the following passes due to the bulging deformation of the sides that accompanies width spread. The mechanism by which the edge-seam defect occurs is shown schematically in **Fig. 10**. **Photo 1** shows the properties of the surface and cross section of SUS430 after the material was rolled from a thickness of 100 mm to 6 mm in six passes by hot rolling with a laboratory mill. Wrinkles can be observed on the side, and it can be understood that those wrinkles have also been folded over onto the strip edges. Thus, the mechanism of edge-seam defects can be divided into two steps: one step in which wrinkles form on the sides of the slab, and a second step in which the wrinkles are folded onto the strip surface layer. Accordingly, to control the edge-seam defect in the process itself, it is important to control the bulging of the slab sides. Therefore, a technology which reduces the folding of wrinkles that occur on the slab sides onto the strip surface was developed and applied. In this method, the slab sides are formed in advance into a concave shape by an appropriate amount which corresponds to the bulging that occurs in horizontal rolling with the rougher mill.

3.3.2 Control of edge-seam defects

At Chiba 3HOT, the strip width is controlled using a sizing press with horizontally opposed anvils. By giving the anvils of the sizing press convex shape, it is possible to impart a concave shape to the sides of slabs, and thereby to reduce the size of the edge-seam defect. **Figure 11** is a schematic illustration of a width press which employs convex anvils.

Figure 12 shows a comparison of the distance from the strip edge to the edge-seam defect with a width press

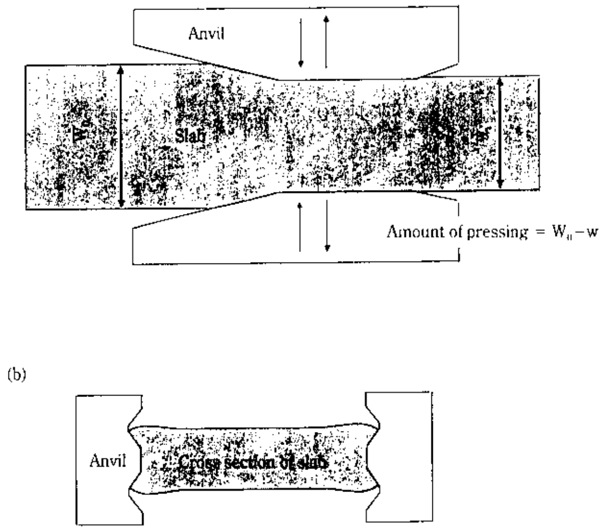

Fig. 11 Outline of width press system by using convex anvil (a) ground plan, (b) cross section

using convex anvils, and that with plain anvils. The figure also includes the case of Chiba No. 2 strip mill, where width control is performed using only an edger. When plain anvils are used and the amount of width reduction by the sizing press is in the range of 80–100 mm, the size of the edge-seam defect (distance from the product edge to the edge-seam) is more than 20 mm per side. In contrast, the size of the edge-seam defect is reduced by approximately half by using the convex anvils. In comparison with the conventional Chiba No. 2 hot strip mill and the case of using plain anvils, the size of the edge-seam defect has been greatly reduced. Moreover, with the plain anvils, the size of the edge-seam defect increases as the amount of width reduction by the sizing press increases. However, this increase can be controlled to a small amount by sizing with convex anvils.

4 Conclusion

The dimensional and flatness quality and surface quality of hot rolled stainless steel strip at Chiba Works No. 3 hot strip mill, which began operation in May 1995, have been dramatically improved by high accuracy, high response gauge control, high accuracy crown and flatness set-up control and dynamic control with pair cross mills, and control of edge-seam defects. The benefits of these quality control technologies are summarized below.

(1) The available size range of stainless steel, which is a hard-to-roll material with high deformation resistance, has been expanded, and high thickness accuracy has been achieved over the full length of the product.

(2) A high accuracy crown and flatness control technol-

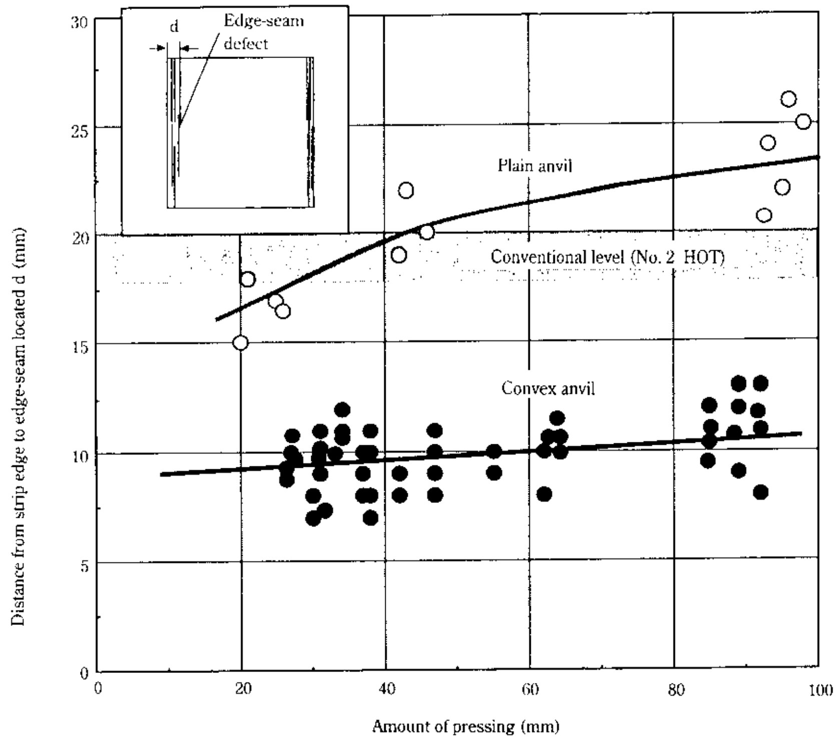

Fig. 12 Comparison of distance from strip edge to edge-seam located between using plain and convex anvil

ogy for stainless steel strip, which stably achieves a low crown even in schedule free operation, was developed.

(3) A technology which greatly reduces the size of edge-seam defects was developed by practical application of the sizing press.

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