

Progress in Sizing Press for Hot Strip Mill Line

TAZOE Nobuhiro : Manager, Control and Management Department, IMEC Corporation

DODO Yasushi : Manager, Machinery Engineering Department, IHI Metaltech Co., Ltd

NISHII Takashi : Manager, Production Technology Development Department, Production Engineering Center, Corporate Research & Development

The first slab-width sizing press at the Kashima Works of Sumitomo Metal Industries was installed in 1985. 13 similar presses have been installed and operated at steel producers during the last 20 years. Before the emergence of the sizing press, Hot Strip Mill (HSM) lines consisted of multiple vertical and horizontal rolling mill stands. This vertical and horizontal combination had many technical problems. Many model tests and numerical analysis were required, as were newly designed equipment based on the results obtained from the tests and analyses. This paper describes the progress in the use of HSMs and the advantages of the sizing press together with equipment features and slab deformation characteristics after the press process.

1. Introduction

Originally, IHI had a proven track of delivering free forging equipment as well as rolling mills, and as of late 1980 had delivered 500 stands of free forging equipment. Especially before the emergence of slab-width sizing presses, "Research on Super Free Forging"⁽¹⁾ was conducted from 1977 as a large-scale project by the former Agency of Industrial Science Technology, Ministry of International Trade and Industry, and forging presses with horizontally counter-moving anvils were then developed for several years.

During this period, IHI designed, produced, and installed a fully-automatic mechanically and hydraulically operated 200 t press in its own factory, mainly for the purpose of conducting forging experiments with round and rectangular objects. After this national project was completed, the press, which was also able to forge plates, was purchased in order to conduct hot steel model experiments of a size was about one-fourth of that used with operating slab-width sizing presses, and as a result fundamental data on material deformation and pressing loads was successfully collected, greatly helping in slab-width sizing presses design.

IHI installed its first slab-width sizing press in the hot strip mill at the Kashima Works of Sumitomo Metal Industries in April 1985.⁽²⁾

In the past 20 years since the first installation, the installation of a slab-width sizing press at the exit of the heating furnace of a hot strip mill line by revamping the hot strip mill line or installing a new hot strip mill line has become a global trend, and it would not be an exaggeration to say that installing slab-width sizing

presses in hot strip mill lines has become mainstream practice.

This paper describes first the background to the introduction of press equipment, the production speed of which was a matter of concern, into the conventional hot strip mill lines that were mass-producing strips with rolling equipment (rolling mills) only. This paper then demonstrates that this forging method is very effective in respect of material deformation by using three-dimensional material deformation analysis. This paper also introduces the latest sizing press model, with regard to which IHI has a track record of delivering 13 units worldwide in the past 20 years after its first sizing press was installed, and explains the future prospects for this technology.

When the first slab-width sizing press was developed, IHI and Sumitomo Metal Industries were given the JSME (The Japan Society of Mechanical Engineers) MEDAL for the Development of New Techniques award in 1994.

2. Background to the emergence of sizing presses

The following describes the background to the emergence of sizing presses in hot strip mill (hereinafter called HSM) lines.

Originally, large-sized caliber edgers (sizing mills) with a bottom diameter of $\phi 1\ 200$ mm were used for slab-width sizing, and their advantage with regard to material deformation brought about the emergence of caliber rolls with a very large diameter, $\phi 2\ 200$ mm. IHI then verified with model experiments and in other ways that preforming width press of slab top and tail⁽³⁾ (used to press the top and tail portions of a slab to reduce its

width before edge rolling) was effective in reducing top and tail crops (which cannot be used as a product and are disposed of as scrap metal), and there was a period when proposals were made to some steel makers to the effect that they adopt top and tail pre-forming width presses in their hot strip mill lines.

Although a caliber edger having a diameter larger than $\phi 2\ 200$ mm was considered to be more advantageous with regard to material deformation because the contact arc length with the material became longer, the diameter of the edger was limited to $\phi 2\ 200$ mm or so because of factors such as lack of manufacturability, transportability, and handling performance in replacing rolls. After the emergence of preforming presses in bloom (a large rectangular semi-finished product) production lines before their emergence in slab production lines, it was recognized that in heavy width draft (heavy width reduction) and a longer contact arc length between the anvil and material was more advantageous with respect to material deformation. The age of full-length slab-width sizing presses then began.

2.1 Before the emergence of sizing presses (1970s)

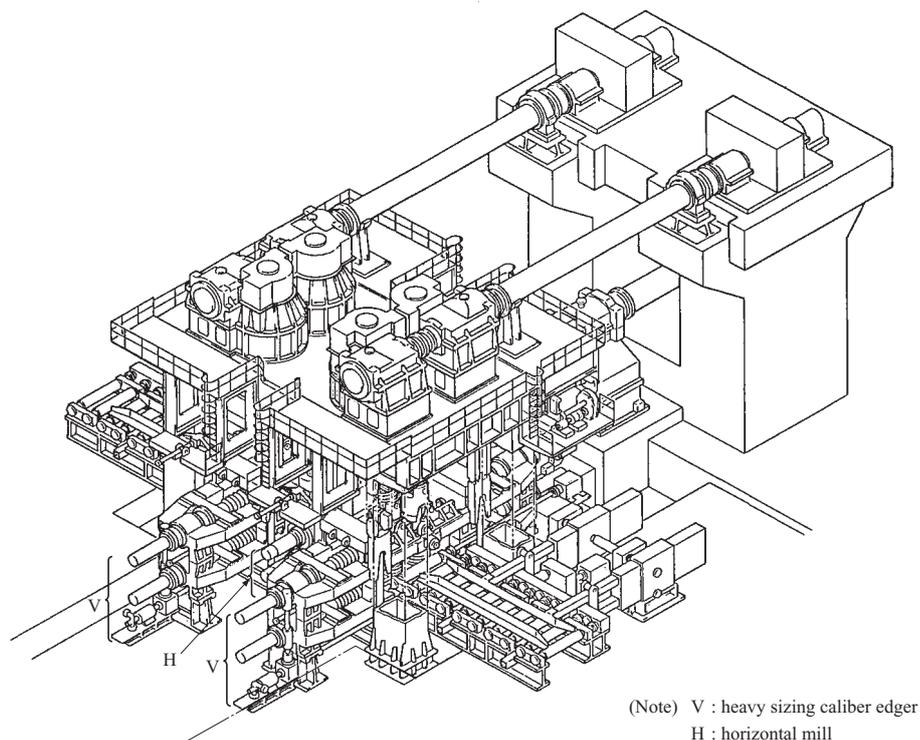
In the mid-1970s, the continuous casting method became widespread in Japan as an alternative to the conventional steel making and blooming processes, and accordingly, hot slabs were gradually replaced by continuous casting slabs. However, because changing the slab size required the replacement of fixed width dimension molds, hot slabs, which required various slab-width sizes, required the casting lines to stop every time the molds were replaced, resulting in reduced productivity and yield.

To solve these problems, studies on a technique to change slab-width in-line at the continuous casting side (a technique to change the width without stopping the production line by adopting a width changeable mold) and a technique to significantly reduce slab-width at the downstream HSM side (initially, heavy size vertical mill: heavy width draft technique using sizing mills) were promoted at the same time. However, both these techniques had problems. Because a width-changeable mold⁽⁴⁾ gradually formed molten steel into solidification cells to produce slabs, the mold width could not be changed drastically during continuous casting. This caused three problems; ① a slab was tapered until the target width was achieved; ② the tapered portions needed to be removed by the vertical mill (edger) in the HSM line; and ③ during intensive edging, fishtails (unstationary top and tail crop looks like a fish tail) occurred at the top and tail portions of the slab, resulting in reduced yield.

2.2 Emergence of off-line sizing mills (Early 1980s)

Because the technologies progressed rapidly and HSM lines were used to mass-produce strips, high priority was given to the development of width-sizing technology. As a result, IHI designed, produced, and delivered sizing mill equipment (full-scale slab-width changing equipment) to the continuous casting plant in the Oita Works of Nippon Steel Corporation in 1980. **Figure 1** shows the appearance of the sizing mill.

This production line was a large-scale, triple tandem piece of equipment consisting of V (heavy sizing caliber edger), H (horizontal mill), and V, which were each



(Note) V : heavy sizing caliber edger
H : horizontal mill

Fig. 1 Appearance of slab-width sizing mill

equipped with 5 000 kW motors. At the continuous casting side, only slabs with a maximum width of 1 900 mm were produced, and the sizing mill took charge of the many slab-width sizes for HSM. Moreover, this full-scale large slab-width changing equipment employed long slabs to improve productivity and reduce top and tail crop loss.

Almost thirty years after its installation, this equipment is still operating reliably.

2.3 HSM in-line sizing mill

Subsequently, there was a period when the VSB (Vertical Scale Breaker), a light width draft edger installed at the head of conventional HSM lines, was replaced by a new sizing mill which was able to significantly reduce slab-width. The amount of slab-width adjustment performed by this sizing mill was 300 mm, and a super-large diameter caliber roll having a (bottom) diameter of $\phi 2\ 200$ mm was introduced in the Hirohata Works of Nippon Steel Corporation.

This is because such a super-large diameter roll is advantageous with respect to rolled slab material deformation. More specifically, there were several advantages: for example, top and tail crops could be reduced; as could the height of the raised portions, the “dogbone”, at the slab-width edges after width reduction, or a smooth dogbone shape could be obtained, providing high width adjustment efficiency (in subsequent thickness reduction, the width spread would be smaller).

After that, IHI exported this $\phi 2\ 200$ mm super-large diameter sizing mill to South Korea.

The installation of a full-scale top and tail preforming press in a HSM line was not realized. This is because sizing mills were soon replaced by sizing presses, and a relatively large capacity was required to press only the top and tail of slabs, increasing equipment costs. However, the top and tail preforming press was put into practical use for bloom production lines that require a relatively low capacity press. IHI also has a track record with regard to the delivery of such presses.

2.4 Emergence of sizing presses (late 1980s)

2.4.1 Study of the fundamental structure of presses

As described so far, IHI had conducted hot steel model experiments, and had newly adopted the rigid plastic finite element method analysis as its first development step, and clarified the basic characteristics of material deformation and press loads. As a result, it was possible to be predicted that in a comprehensive comparison, the press method would have an advantage over the sizing mills were in operation.

However, introducing press equipment into highly productive HSM lines in Japan caused several problems, so further study was required.

Table 1⁽⁵⁾ shows some of the results of study on the ideal fundamental structure of sizing presses in order to put them into practical use.

- (1) Pressing draft - slab transfer method

Compared with conventional edger roll methods, the press method had problems with regards to production speed. With start-stop type presses, it is necessary to rapidly accelerate and decelerate slabs weighing 30 t using a transfer system (pinch rolls) every time pressing is carried out. This could cause scratches on the slab and pinch rolls if scale is present thereon. In addition, if a pinch roll exerts an excessively large holding force scratches could also be caused; if the press cycle time is increased, because of start-stop type presses having the above mentioned restrictions, hot strip production capacity will decrease.

Increasing press cycle time will also increase the time when the anvil is in contact with the vertical surface of the slab-width edge, causing the temperature of the vertical surface of slab-width edges to drop; and there is a concern that the temperature of the anvil will increase, causing thermal fatigue.

Due to the above-mentioned points, the development of flying type presses, which can press slabs without stopping them, was considered essential.

(2) Buckling prevention system

Generally, subjecting a wide slab to a single width draft exceeding 300 mm will cause the slab to easily buckle in the width direction. It has been confirmed with hot steel model experiments that the top and tail portions of a slab buckle significantly, especially when the slab is not connected to other materials at the top and tail; therefore, it is necessary to install holding rolls to prevent buckling.

The structure of the equipment should be as simple as possible. It was confirmed with hot steel model experiments that installing a pair of rolls having a large diameter of $\phi 800$ mm or so at the upper and lower side would make it possible to prevent buckling even when the slab-width was significantly reduced.

It was also found that the holding roll could be optimally positioned in the longitudinal direction, to prevent buckling.

As a result of further study, the world's first flying mechanical high speed press with horizontally counter-moving anvil, as mentioned below, was successfully produced.

2.4.2 Main specifications of sizing presses

The main specifications are as follows:

Type	Flying mechanical press with horizontally counter-moving anvil width reduction
Driving method	Top drive method with mechanical crank running to the rolling direction
Running method	Mechanical crank method, with mechanism adjusting running velocity to the rolling direction



Fig. 2 Slab-width sizing press

sizing presses have been continuously modified and improved to achieve higher quality, and now the thirteenth sizing press has been installed at the West Japan Works of JFE Steel Corporation.

The following explains how equipment development has progressed to date since the first sizing press was developed, and also describes the latest sizing press equipment and recent trends.

3.1 Shift from developed equipment to production equipment

The development of the in-line flying mechanical press with a horizontally counter-moving anvil for HSM was successfully completed after many experiments and tests and the elimination of the problems described in **Section 2.4**.

However, it was not easy to stably operate equipment that repeats 2 700 t width adjusting operations 50 times per minute (once every 1.2 seconds). There was a period when engineers struggled more with the pressing loads applied and released repeatedly in a short time, vibrations generated by the draft load, steam generated from cooling water sprayed to protect the equipment, and Radiation heat from slabs, than they did with conventional rolling mills. Moreover, it took a lot of time to design the mechanism to adjust the gap in the rotating and sliding portions, and solve lubrication-related problems, as many sliding elements were required to realize the unique flying press.

The equipment developed went through major structural changes and progress took place through trial and error, and the current fundamental structure was determined when the fifth sizing press was installed at Kurakatau Steel (Indonesia). Since then, no major changes have been

made to the fundamental structure.

3.2 Recent sizing press equipment

Although no major changes have been made to the fundamental structure since the fifth sizing press started its operation, sizing presses have been improved to prevent corrosion and abrasion, extend the service life of consumable parts and enhance serviceability, as the number of sizing presses increases.

For example, the latest sizing presses installed at China Steel (Taiwan), the twelfth and thirteenth, and the West Japan Works of JFE Steel Corporation have been operating smoothly and without trouble since they started operations in 2005. This is all because detailed improvements and measures based on the maintenance information provided by the users have born fruit.

Some sizing presses have been operating for more than 10 years, making it possible to statistically organize maintenance data. Secular changes in vibration and temperature have been monitored by equipment diagnostic sensors, and the regular replacement cycles of consumable parts have been organized based on the past data with a shift from “replacing broken parts” to “replacing parts on a periodic basis before they break down.” Moreover, it is becoming common to partially assemble major spare parts before they are stored and replace them as a unit so that production line downtime can be minimized.

4. Progress of development techniques

4.1 Analysis of width sizing presses

When the sizing press was developed, its basic characteristics such as material deformation characteristics and load characteristics were determined

mainly based on the results of experiments using lead materials and hot steel. Currently, the prediction of deformation and load characteristics by simulation has become common because of the development of simulation techniques using three-dimensional CAD and CAE, which has become essential to the product development of plastic working machines, in particular. The following shows examples of the results of analyzing the characteristics of width-sizing presses using general-purpose plastic working analytical software.

Figure 3 shows the analytical model of a width-sizing press. The analytical model is a vertically and horizontally symmetrical quarter scale model that has an anvil behaving in the same manner and at the same speed as the actual equipment and that is able to mimic the deforming process using the flying press. **Figure 4** shows an example of three-dimensional analysis of a width-sizing press. This shows steady state deformation and stress distribution in the width direction when some low-carbon steel plate having a width of $\phi 1\ 200$ mm and thickness of 250 mm, and with a carbon content of 0.05%, is pressed to reduce its width by 350 mm. The slab temperature is 1 375 K, $\bar{\sigma} = 90.5(\bar{\epsilon} + 0.001)^{0.21} \bar{\dot{\epsilon}}^{0.13}$ Mpa

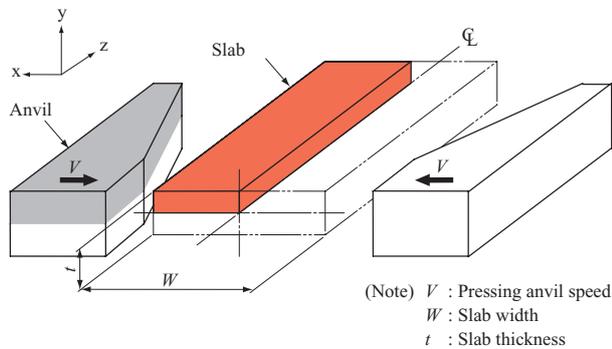


Fig. 3 Analysis model of slab-width sizing press

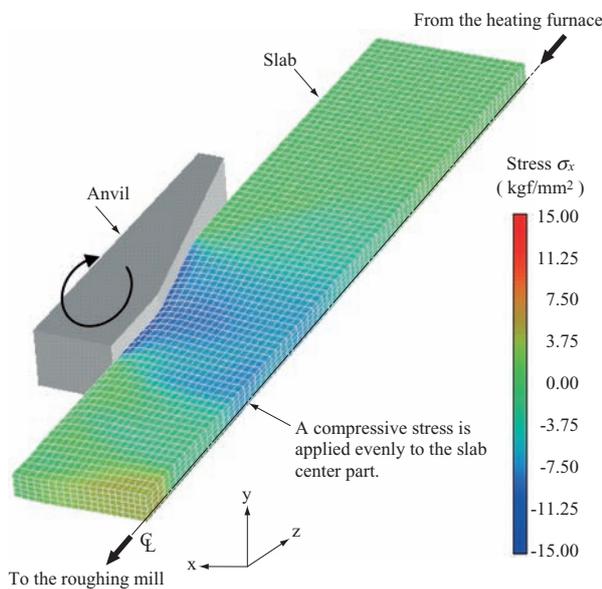


Fig. 4 3D analysis of slab-width sizing press

the deformation resistance the slab feed per press is 400 mm, and the friction coefficient between the slab and anvil is 0.3. **Figure 4** shows that a high compressive stress is applied to the slab-width center.

Figure 5 shows the cross-sectional deformation characteristics of a width-sizing press. This figure shows the analytical results of the cross-sectional deformed geometry when quarter-scale hot steel (low-carbon steel plate having a width of 400 mm and thickness of 60 mm, and with a carbon content of 0.15%) is pressed to reduce its width by 75 mm (equivalent to a width draft of 350 mm with the operating equipment). This figure shows that although a single bulge is observed in the non-steady region at the slab top end, a double bulge, a “Dogbone” shape, is observed in the steady region where the processing has progressed further. **Figure 6** shows a comparison with the results of the experiment conducted with a hot steel model under the same conditions.

These results show that the simulation results and experiment results match well, and single bulges in the non-steady region and double bulges in the steady region can be reproduced well by the simulation.

4.2 Analysis of continuous width sizing presses

A sizing press continuously presses slabs while feeding them at a predetermined speed. The following shows the results of the analysis of continuous pressing in which the slab top end was first pressed into a steady state (normally, through being pressed three or four times), conducted using the rigid plastic finite element method software developed by IHI.

Figure 7 shows the result of the analysis of a continuous width-sizing press. This figure shows the stress distribution in the width direction when a slab is pressed four times from the slab top end. It can be seen from this figure that the non-steady region at the slab top end

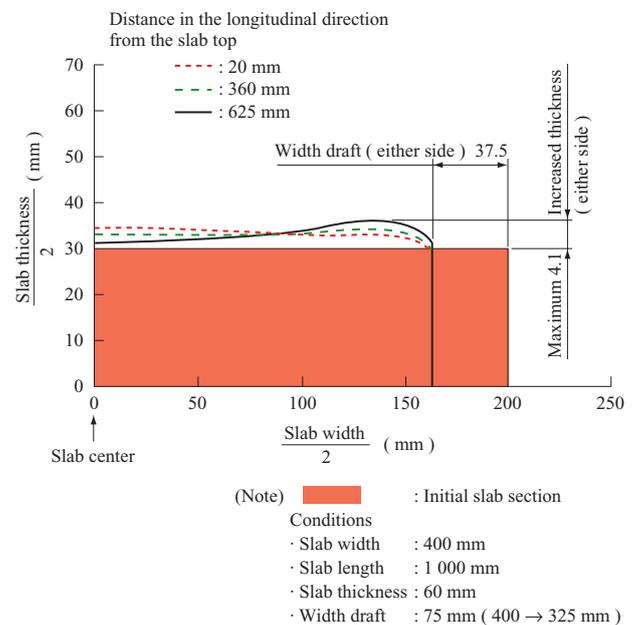


Fig. 5 Sectional deformation characteristics of slab-width sizing press

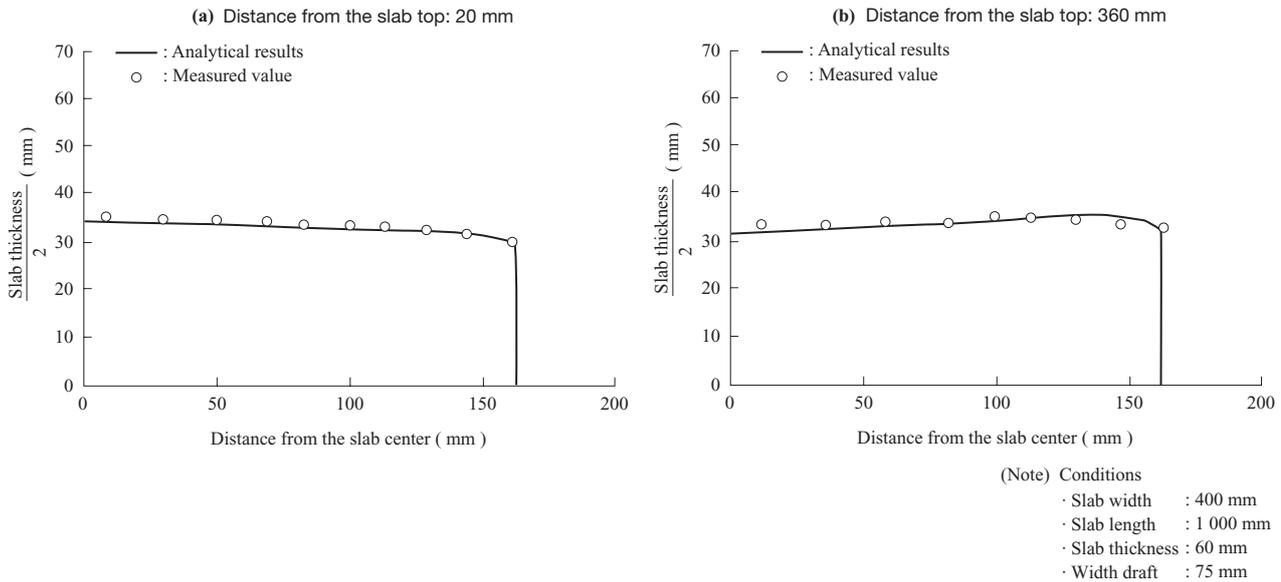


Fig. 6 Comparison between analyses and experiments on a slab-width sizing press

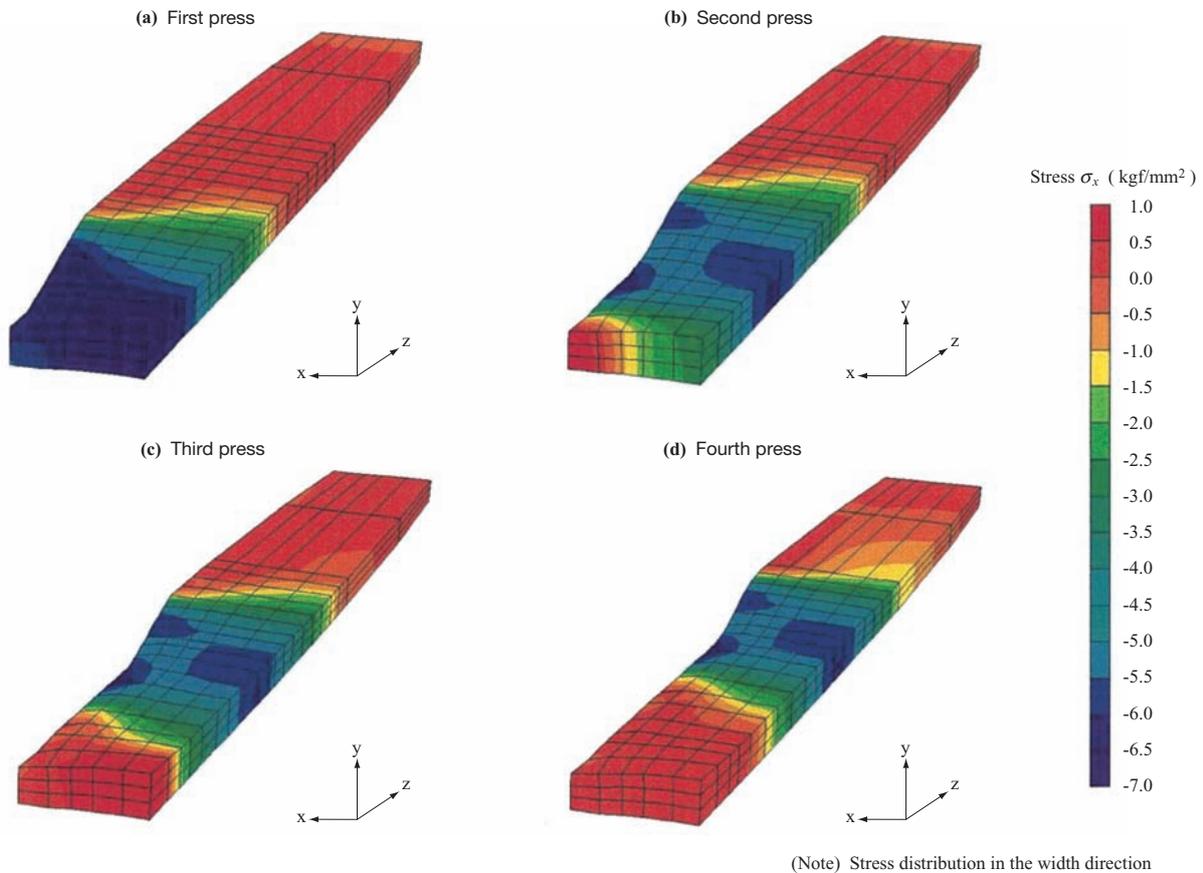


Fig. 7 Analytical results of continuous slab-width sizing press

becomes steady when the slab is pressed three or four times. **Figure 8** shows the transition in the stress applied to the slab-width center in the width direction.

This figure shows the result of observing the stress applied to the slab-width center in the longitudinal

direction. It can be seen from this figure that a high compressive stress is effectively applied to the slab-width center. This demonstrates that the slab feed of 400 mm, recommended by IHI, is efficient in respect of internal quality improvement of slabs.

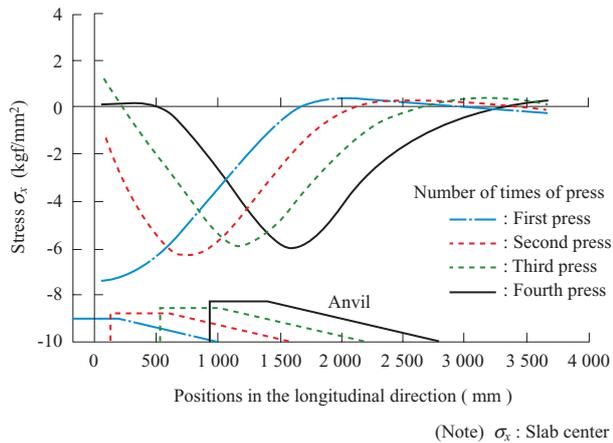


Fig. 8 Stress distribution to width direction in continuous slab-width sizing press

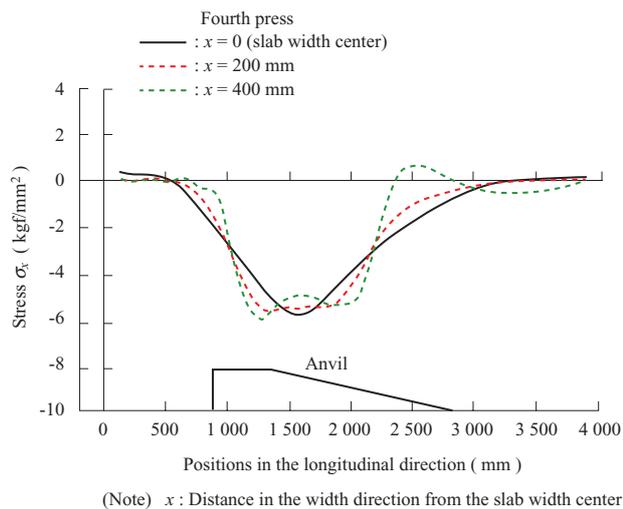


Fig. 9 Stress distribution to width direction in slab-width sizing press under the normal condition

Figure 9 shows the stress distribution in the width direction in steady state (when the slab is pressed four times). A stress (σ_x) is applied in the longitudinal direction to the slab center, and to positions 200 and 400 mm in the width direction from the slab width center. It can be seen from this figure that a compressive stress is applied evenly to the center and edges of the slab width.

5. Conclusion

More than twenty years have passed since the first width-sizing press started operation, and it has become common to introduce sizing presses into mass-production HSM lines, where rolling deformation had been performed

using rolls only.

Before that time, a super-large diameter sizing mill emerged, having a bottom diameter of $\phi 2\ 200$ mm, which was the largest among large-sized vertical rolling mills for width reduction.

It was anticipated that a larger diameter would be more of an advantage with respect of deformed materials. Since then, however, no roll edger with a larger diameter has emerged mainly because of manufacturing and transport limitations, and the large diameter sizing mill was replaced by a next-generation sizing press.

IHI developed a flying mechanical press with a horizontally counter-moving anvil, which enabled continuous pressing without stopping slabs so as to prevent the temperature drop at the slab edges during pressing, and which is therefore suitable for mass production. Currently, 13 sizing presses of this type are in operation in Japan and worldwide. IHI has also been developing a thickness reduction press by applying its sizing press technologies, and has been verifying its effectiveness.

It is expected that new HSM lines will continue to be installed and that existing HSM lines will be revamped all over the world. IHI therefore intends to make every effort to expand its sales of sizing presses and other equipment by making full use of its accumulated techniques and experience.

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