Outline of Free Size Rolling for Hikari Wire Rod and Bar Mill

1. Introduction

The Hikari Wire Rod & Bar Mill began commercial operation in 1955 as Japan's first fully continuous wire rod mill (for carbon steel). The Mill started production of stainless steel wire rods in 1963. Today it is dedicated to the production of stainless steel bars and wire rods.

In the meantime, various improvements were introduced in the Mill. For example, the processes after the No. 2 intermediate train were modernized in 1981 and in-line solution treatment was introduced in 1982. In 1995, new technologies to reinforce the Mill were developed and introduced. They include the highly efficient billet heating system (a complex heating system that combines a walking beam-type reheating furnace and an induction heater) for improving product quality, and the helical rolling mill for implementing an in-line blooming process.

Stainless steel bars and wire rods which undergo secondary and tertiary forming processes are widely used in the forming of screws, bolts, pins, shafts, springs and welding rod for automobiles, office automation equipment, etc. Because of their many uses, stainless steel bars and wire rods are manufactured in a wide variety of grades. Thus, they are characterized by small volume production in various sizes and grades.

At the Mill, wire rods (5.5- to 34-mm ϕ) and bars (22- to 62-mm ϕ) are rolled by one strand. Wire rod is finish-rolled by a no-twist mill (NT mill) and wound by a laying head. A thicker wire rod (bar-in-coil) is wound on a pouring reel, and bars are pooled on a cooling bed installed on a line branched out from the intermediate train for rolling wire rods (see **Fig. 1**).

In recent years, market demand for stainless steel products has become increasingly rigorous. Accordingly, the demand for higher dimensional accuracy, shorter delivery time and fewer surface defects in stainless steel bars and wire rods as materials for stainless steel products has become conspicuous.

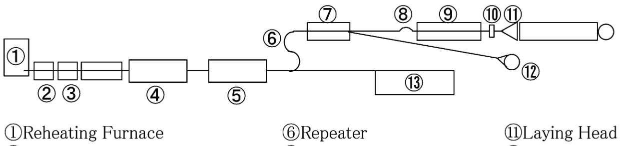
Under such conditions, to improve product quality and productivity, we introduced a high-rigidity, 3-roll mill (reducing/sizing mill: RSB) made by Kocks and a new type of conveyor line in November 2002.

Looking at the rolling equipment, the RSB was installed after the intermediate train as the finishing mill for thicker wire rods and bars to improve their dimensional accuracy and implement size-free rolling. In addition, the dimensional accuracy of thinner wire rods was improved by stabilizing the dimensions of steel material at the NT mill entrance after introduction of the RSB. Furthermore the time required for roll changing was shortened by adopting roll assemblies for the RSB rolling stands.

As a measure to reduce surface defects, the repeater that had been used to guide the steel from the intermediate train to the pre-finishing mill was replaced with a new conveyor line using continuous roller guides.

As a result of the above modifications, we were able to improve the dimensional accuracy, shorten the roll-changing time by implementing size-free rolling, and reduce surface defects.

In this paper, we describe in detail the modification work, with the focus on development of the technology for size-free precision rolling that was industrialized for the first time in the world through introduction of an RSB.



①Reheating Furnace
②Induction Heater
③Planetary cross rolling Mill
④Roughing Train
⑤Intermediate Train
⑥Repeater
⑦Pre Finishing Mill
⑧Side Looper
⑨NT Mill
⑩Profile meter
⑪Laying Head
⑫Pouring Reel
⑬Cooling Bed

Fig. 1 Layout of Hikari Wire Rod & Bar Mill before installation of RSB

2. Basic Concept

To meet increasingly rigorous customer needs, at the Wire Rod & Bar Mill, we decided to reinforce the overall capabilities of the rolling lines from the following standpoints.

1) Improving the dimensional accuracy of all products—thin wire rods, thick wire rods, bars (the difference between maximum diameter and minimum diameter within 0.15 mm)[1].
2) Implementing size-free rolling (i.e., rolling products of varying sizes without changing rolls) on a 3-roll mill while meeting this requirement: diameter difference $\leqq$ 0.15 mm, within 9% of diameter for rolling sizes < 34-mm ϕ and within 1.5 mm for rolling sizes $\geqq$ 34-mm ϕ .
3) Improving the productivity by speeding up the roll-changing work (shortening the roll-changing time).
4) Improving the product surface quality by preventing the occurrence of surface defects during transportation in the rolling process.

To meet all the above objectives, we decided to install an RSB after the intermediate train. The RSB permits using either a pinpoint caliber having grooved rolls for each different rolling size to allow for precision rolling or a size-free caliber. We adopted the size-free caliber to implement size-free rolling.

Since thick wire rods (16- to 34-mm ϕ) and bars are finished by the RSB, size-free rolling can be applied to them. For thin wire rods finished by the NT mill, it is possible to improve the dimensional accuracy of the entry steel material.

The dimensional accuracy of steel products finished by the NT mill depends on the dimensional accuracy of the entry steel material and the characteristics of the NT mill. During a preliminary study, we conducted a rolling test on an actual mill using entry steel materials of varying dimensional accuracy. As a result, we confirmed that by using entry steel material with a high dimensional accuracy, it was possible to improve the dimensional accuracy of NT mill-finished steel products, that is, thin wire rods. Thus, by installing the RSB after the intermediate train, it was possible to improve the dimensional accuracy of all wire rods (5.5- to 34-mm ϕ).

For steel products finished by the NT mill, it is necessary to transport them from the RSB exit to the NT mill. To prevent slide marks on them during transportation, we decided to adopt a new conveyor line using continuous roller guides.

3. Basic Specifications

Fig. 2 shows the layout of the rolling line after the modification. The layout of the new facilities has the following characteristics.

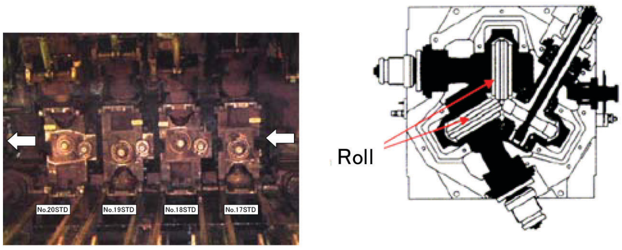
1) The RSB was installed after the intermediate train to permit improving the dimensional accuracy of all sizes of products.
2) The steel product is transported from the RSB to the NT mill by a new conveyor line using roller guides to prevent it from sliding over the conveyor line. This new conveyor line was connected to the existing conveyor line. In addition, the conveyor line from the RSB to the pouring reel was renewed.
3) The No. 1 profile meter was newly installed after the RSB to permit feeding back dimensional data to the RSB rolling process.
4) The RSB installation work was conducted during operation of the existing rolling line to minimize the production stoppage period.

4. Contents of Modification of Rolling Equipment

4.1 Outline of modification

The principal specifications of the RSB introduced are shown in **Table 1**, and its appearance is shown in **Fig. 3**. The salient features of the RSB are as follows. All these features address the purposes of the modification.

1) Since the RSB is a 3-roll type mill, the spread ratio of rolled steel is smaller than that on a 2-roll type mill. This is suitable for rolling with high dimensional accuracy (see **Fig. 4**)[2].
2) The three-shaft drive system eliminates the need for the bevel gears inside the rolling stand, and the increased roll shaft diameter gives a high stiffness of 250 tons/mm to the roll. These are also suitable for rolling with high dimensional accuracy.
3) The stand-to-stand distance is comparatively short (720 mm). This is advantageous from the standpoint of preventing the steel material from buckling and falling.
4) The gap between the roll and the guide roller can be varied in increments of 0.01 mm by remote operation.
5) In order to implement size-free rolling, an independent drive system in which each of the four stands is driven by a motor was adopted. Therefore, there is no need to use rolls of the same diameter in the individual stands.
6) The rolling stands are of a unit type and can be changed all at once. The time required for changing stands on-line is about five minutes.



a) Appearance of RSB stand   b) Cross section of RSB stand

Fig. 3 Appearance of RSB

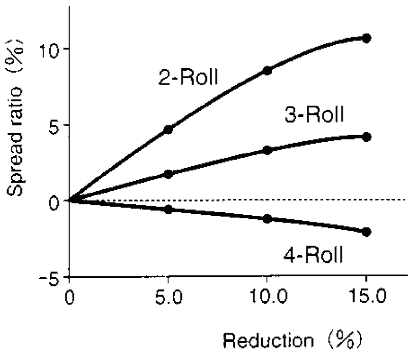
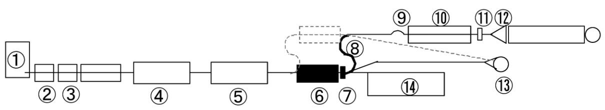


Fig. 4 Spread ratio[2]



①Reheating Furnace
②Induction Heater
③Planetary cross rolling Mill
④Roughing Train
⑤Intermediate Train
⑥RSB
⑦No.1Profile meter
⑧New Trough Line
⑨Side Looper
⑩NT Mill
⑪No.2Profile meter
⑫Laying Head
⑬Pouring Reel
⑭Cooling Bed

Fig. 2 Layout of Hikari Wire Rod & Bar Mill after installation of RSB

4.2 Development of size-free rolling technology

4.2.1 Outline of size-free rolling

Size-free rolling means rolling steel materials of varying cross-sectional sizes using a single grooved roll. In the 3-roll method, the entire circumference of the steel material is rolled by three grooved rolls, and the scope of forming by each grooved roll is narrower than that in the 2-roll method. Therefore, the deterioration of center sym-

Table 1 Specifications of RSB

Stand	Roll (mm ϕ)	Motor (kW)	Base/top (rpm)	Gear ratio	Interval (mm)	Manufacturer
17	380×75	DC450	650/1 750	1/4.63, 1/2.43	720	Kocks GMBH & Co. (Germany)
18	380×75	DC750	500/1 000	1/2.16, 1/1.18	720	
19	380×75	DC450	650/1 750	1/4.64, 1/1.92	720	
20	380×75	DC200	650/1 750	1/4.64, 1/1.92	-	

metry during roll gap change is small. In addition, as shown in Fig. 4, the spread ratio of steel material in the 3-roll method is smaller than that in the 2-roll method. Because of these characteristics, the 3-roll method is more suitable for size-free rolling.

4.2.2 Requirements for size-free rolling

The RSB uses a high-reduction pass in the first two stands and a low-reduction forming pass in the latter two stands. In particular, in the final stand, the RSB rolls the steel material with a reduction rate of 2% to 6%, at which the spread ratio is small, to secure high dimensional accuracy. To ensure the desired dimensional accuracy, the grooves in the rolls of the last two stands resemble a circular arc. Because of these characteristics, to implement size-free rolling, it is necessary to meet all the following requirements.

1) Adoption (optimization) of free-size groove

Based on the results of calculations for profile prediction by general-purpose FEM software[3, 4], we optimized the free-size groove shape and rolling conditions, such as the roll gap and roll speed using our own software.

2) Independent roll speed control on each stand

To eliminate the limitation on the reduction distribution, we adopted an independent drive system for each stand to permit controlling the roll speed on each stand independently.

3) Prevention of twisting/falling of steel material in the forming process

From the standpoint of securing high dimensional accuracy of rolling steel material in a region in which the spread ratio is small, it is advantageous to lower the reduction rate in the forming pass. In this case, however, the phenomenon whereby the steel material twists during rolling on the final stand and the steel surface formed in the preceding stand is re-formed tends to occur easily. If this phenomenon occurs, the shape and dimensional accuracy declines markedly.

In the RSB, the rolled steel material is held by a roller guide at the entrance to each stand. **Fig. 5** schematically shows how the steel material is held by the roller guide. In a high-reduction pass, since the roundness of the steel material is low as shown in Fig. 5 a), it can easily be held and the above phenomenon hardly occurs.

With pinpoint rolling, the reduction rate on the final stand is about 6% as shown in **Table 2**, and hence the above phenomenon hardly occurs.

In size-free rolling, by contrast, the steel material at the entrance to the final stand on which the reduction rate is especially low is almost round in cross section. In this case, the resistance of friction between the roller and the steel material is the only force that acts to prevent the above phenomenon. Therefore, if the guide roller opens slightly, it fails to hold the steel material securely, causing the above phenomenon to occur easily.

4.2.3 Improved guide rollers

When the above phenomenon occurs, the steel material pushes the guide roller in the direction of the arrows as shown in **Fig. 6**. To hold a virtually round steel material in the guide roller to prevent the phenomenon, it is necessary to increase the spring constant of the guide roller. By so doing, it is possible to support the steel material securely with a large force even if the guide roller opens slightly.

Therefore, we tested various spring constants for the guide rollers to determine the optimum spring constant. As a result, the unwanted phenomenon would not occur as long as the spring constant when a load is applied in such a direction that the guide roller is moved away from the pass line is 30 to 300 kN/mm depending on the rolling conditions. Based on this finding, we increased the spring constant to 300 kN/mm so as to obtain a steel material holding force sufficient to prevent the above phenomenon during rolling in the final pass[5]. This made it possible to ensure proper forming in the last two passes and implement size-free rolling.

4.2.4 Improved guide roller bearings

When the spring constant of the guide holder (roller) is increased, the steel material holding strength of the roller increases accordingly. On the other hand, the load applied to the roller bearings increases,

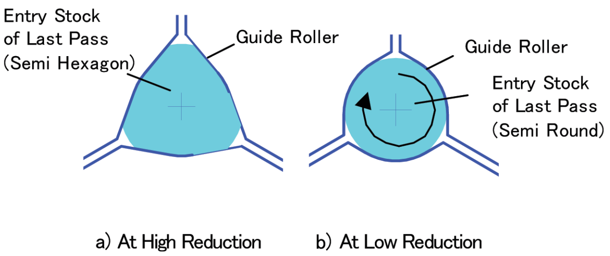


Fig. 5 Guiding condition

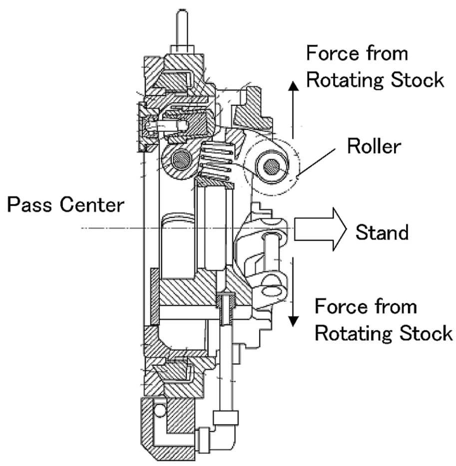


Fig. 6 Cross section of roller guide

Table 2 Stability for rotating at the last pass of RSB

	Reduction of last pass	Shape of entry stock of last pass	Stability for rotating
Precision rolling (not free size)	6%	Semi hexagon	Stable
Free size rolling	6% ↕ 2%	Semi hexagon ↕ Semi round	Stable ↕ Unstable

causing damage to the bearings to occur more rapidly. If the bearings break, the roller stops rotating, causing surface defects to occur due to the friction between the roller and the steel material.

Therefore, we improved the construction of the roller so that bearings capable of supporting a larger load could be applied. In addition, measures were implemented to ensure a stable supply of lubricant to the bearings. All this made it possible to prolong the bearing life while securing a steel material holding force sufficient to prevent the above phenomenon.

4.2.5 Development of tension control between stands

Each of the stands of the RSB introduced is operated independently so as to increase the freedom of speed control for each stand and implement size-free rolling. The speed ratio between stands is inversely proportional to the steel material area ratio. It is constant under fixed rolling conditions (steel material diameter at entrance, grooved rolls used, steel material diameter at exit). Actually, however, the cross-sectional area of the steel material varies due to the change in temperature along the length of the steel material, etc. When a constant rolling speed is used under this condition, the finished product is subject to dimensional fluctuations along the length. To ensure dimensional stability of the finished product, we developed for ourselves a tension controller between stands for the first time as a means of speed control for a wire rod mill.

In this method, the rolling speed at the upstream stand is automatically controlled in such a way that the motor current value at the final stand becomes the preset value. Thanks to this control, even if a minor dimensional change occurs with the steel material at the entrance to the final stand, it can be compensated for by changing the feeding speed of the steel material. As a result, we could secure high dimensional accuracy.

5. Modifications to Auxiliary Equipment

5.1 New conveyor line

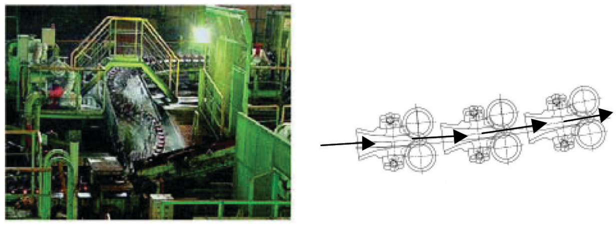
The pass line of the NT mill is about 2 m higher than the pass line leading up to the intermediate train. They are horizontally separated from each other. Until introduction of the RSB, steel material had been guided from the intermediate train to the pre-finishing mill (PFM) by a repeater. However, since the repeater could not make the relative speed with the steel material zero on all the pass lines, it was necessary to introduce suitable improvements from the standpoint of preventing surface defects on the steel material.

As the new guiding method, we developed a unique conveyor line using a continuous roller guide. In this method, on the inclined plane including the two pass lines, the steel material is guided along an S-shaped curved line which connects two arcs having a large radius of curvature (see **Fig. 7**). This permits minimizing the bending of the steel material and guiding it smoothly over the shortest distance. By using a large bending radius, it has become possible to prevent misleading of the front end of the steel material, the occurrence of slide marks on the steel material, and a decline in the steel material temperature (thanks to the shortened pass line)[6].

The conveyor line using a continuous roller guide does not have a function to remove the tension that is applied to the steel material being rolled. The removal of tension is performed by the side looper installed in front of the NT mill entrance downstream of the conveyor line.

5.2 Profile meter

To implement rolling with high dimensional accuracy using the



a) Appearance of New Conveyer line　　b) Serial Roller Guide

Fig. 7 New conveyer line

a) Appearance of Profile meter　　b) Display of Profile Meter

Fig. 8 Profile meter located after RSB

RSB, it is necessary to make an accurate on-line measurement of the profile of the steel material being rolled and feed back the measurement data to the appropriate process. Therefore, we installed a LAP profile meter (LAP GmbH Laser Applikationen, Lueneburg, Germany) after the RSB (see **Fig. 8**).

This profile meter is only about 130 mm in length along the line and can be installed very close to the back of the mill. Therefore, it is hardly influenced by twisting of the steel material, etc. In addition, since the profile meter has no moving parts, it is highly reliable. It uses six laser beams to measure profiles and non-revolving light emitting and receptor parts.

6. Effects of Modification

The favorable effects obtained by the modification are as follows.

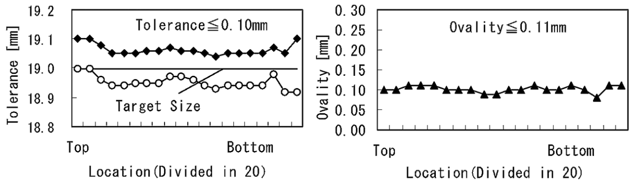
(1) The desired dimensional accuracy could be attained for both the RSB finishing size and the NT mill finishing size.
(2) By implementing size-free rolling, the number of roll types required to roll all sizes of products was reduced by about 40%.
(3) Thanks to integrating the pass schedules, etc., the roll-changing time decreased by about 15%.
(4) The new conveyor line reduced the number of slide marks by about 60%.

6.1 Results of implementing size-free rolling

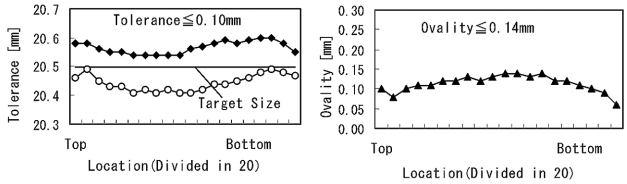
Fig. 9 shows the rolling results for 19.0-mm ϕ and 20.5-mm ϕ wire rods using the same grooved rolls. These two sizes are near the low and high limits of the range of size-free rolling. For both wire rods, the aimed ovality $\leqq$ 0.15 mm was attained. By implementing size-free rolling, it has become possible to subdivide the conventional size pitch of 0.5 mm or 1.0 mm.

6.2 Improvement in dimensional accuracy of wire rods finished by NT mill

By improving the dimensional accuracy of steel material at the

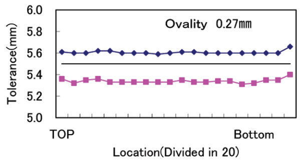


a) Minimum Size of Free Size Range (19.0mmϕ)

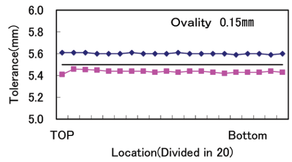


b) Maximum Size of Free Size Range (20.5mmϕ)

Fig. 9 Tolerance & ovality of free size rolling



a) Before installation of RSB



b) After installation of RSB

Fig. 10 Tolerance of wire rod

NT mill entrance, we could improve the dimensional accuracy of wire rods finished by the NT mill as shown in **Fig. 10**.

6.3 Pass schedule

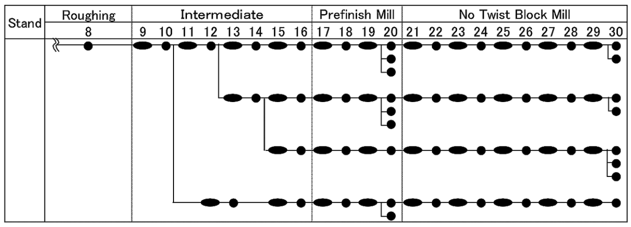
Fig. 11 shows an example of the pass schedule before and after the modification. Thanks to the integration of intermediate trains and the implementation of size-free rolling by the RSB, the number of roll types required to roll all product sizes has decreased from 218 (7 for roughing train, 58 for intermediate train, 63 for PFM and 91 for NT mill) to 138 (7 for roughing train, 12 for intermediate train, 28 for RSB and 91 for NT mill). Thus, the modification has dramatically reduced the number of rolls.

6.4 Stand-changing time

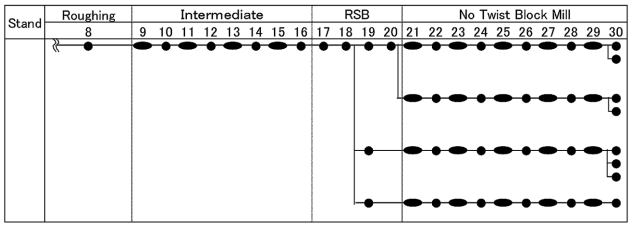
The implementation of size-free rolling has unified pass schedules in the intermediate train. As a result, the number of rolling size changes not requiring a change in the intermediate train has increased. For the RSB, all the stands are changed at once. This has reduced the stand-changing time significantly. With respect to the size change of RSB finishing within the range of size-free rolling, it can be achieved simply by remotely adjusting the roll and roller guide gaps. Thanks to all this, the time required for stand changing has been markedly shortened as shown in **Fig. 12**.

6.5 Reduction of surface defects by introduction of new conveyor line

The conveyor line from the intermediate rolling train to the finish rolling train was replaced with a new type of conveyor line to prevent the steel material from sliding over the rolling line. As a result, the number of surface defects which are considered due to the conveyor line has markedly decreased as shown in **Fig. 13**.



a) Before Installation of RSB



b) After Installation of RSB

Fig. 11 Change of pass schedule

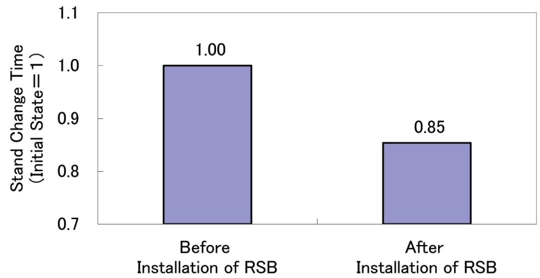


Fig. 12 Time for stand change

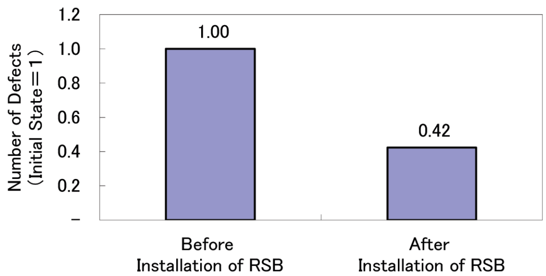


Fig. 13 Number of defects in wire rod

7. Conclusion

At Hikari Wire Rod & Bar Mill, which specializes in the production of stainless steel products, we have introduced various improvements to reinforce its capabilities, such as introducing in-line solution treatment, improving heating efficiency and implementing an in-line blooming process.

By conducting modification work focused on size-free rolling that was successfully implemented for the first time on an industrial basis, we could improve the dimensional accuracy of products, reduce surface defects and improve productivity through curtailment of the time required for stand changing.

We intend to pursue further improvements in order to meet the increasingly diversified needs of our customers.

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For inquiries, please contact:
Hikari Works, Nippon Steel & Sumikin Stainless Steel Corporation