NIPPON STEEL TECHNICAL REPORT No. 126 MARCH 2021

Technology

Rough Rolling Improvement at Wire Rod and Bar Mill in the Hikari Area of Nippon Steel Stainless Steel Corporation

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Abstract

The wire rod and bar mill in the Hikari Area of Nippon Steel Stainless Steel Corporation is continuously working to improve the quality. Problems that have been encountered so far include wrinkle defects, restrictions on the manufacturable range, and optimization of the in-line breakdown process. Optimization was carried out based on comparing the current situation and improvement plans by numerical analysis, using the circumferential compressive strain for wrinkles, the temperature of rolling for expanding the manufacturable range, and the equivalent plastic strain of the surface for the in-line breakdown process as an index. In order to achieve this optimum condition, improvements were made by equipment modification, and wrinkle defects in particular could be greatly suppressed in both number and depth compared to conventional products.

1. Introduction

Nippon Steel Stainless Steel Corporation has only one wire rod and bar mill located in the Hikari Area. The rolling plant has been operating for 58 years since the operation start in 1962. During this period, Nippon Steel Stainless Steel has introduced various technologies such as in-line heat treatment, complex heating, in-line breakdown, and free size rolling. The layout of our rolling line branches out midway so that wire rods, bar-in-coil, and bars are manufactured in one line (**Fig. 1**).

Stainless steel wire rods and bars are processed in the secondary and tertiary work stages. Manufactured fasteners (e.g., screws), pins, shafts, springs, and parts for welding are widely used for automobiles and OA appliances. The material quality needs to be high to prevent problems during processing and use. The required levels of properties related to surface flaws that tend to be the starting points of defects are particularly high and thereby steel manufacturers are demanded to improve the quality continuously. Our wire rod and bar mill in the Hikari Area is specialized in stainless steel on which

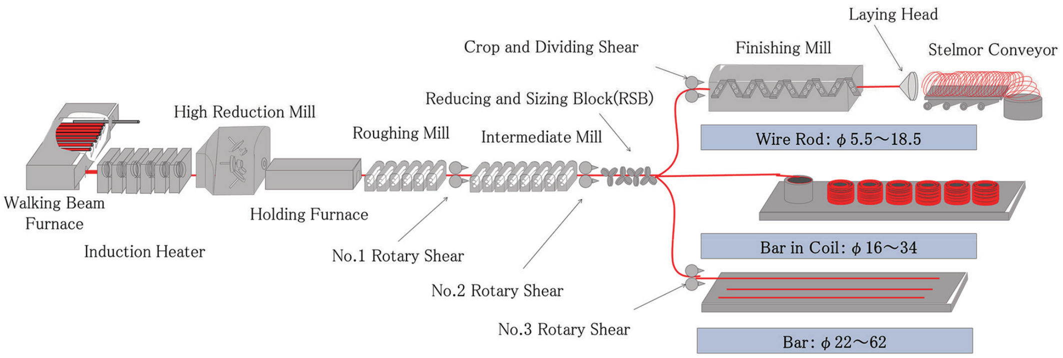

Fig. 1 Layout of wire rod and bar mill

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surface flaws tend to occur and thereby we have been working to prevent such flaws.

This report introduces examples of the latest improvements in the rough rolling.

2. Conventional Problems

2.1 Wrinkle defects

Wrinkle defects refer to flaws made on the surface of steel materials due to compressive strain in the circumferential direction of the materials in the course of area reduction during rolling. Such defects are seen on the entire length of steel materials without interruption (**Fig. 2**). Wrinkle defects are controlled by the shape of rolling passes and area reduction rate. Before basic rolling conditions are changed, the influence needs to be thoroughly considered.

At our wire rod and bar mill, wrinkle defects were found on certain steel grades in pre-shipment inspections. They made stable production impossible since relieving processes needed to be added frequently and discarding was often required.

2.2 Restrictions on the manufacturable range due to temperature decrease during rolling

In continuous rolling that is a characteristic of our wire rod and bar mill, the volume velocity of steel materials is the same at all the rolling stands; the speed is slow in the first stage in which the cross section of a steel material is large and it is fast in the latter stage in which the cross section is small. For steel grades with low hot workability, flaws are sometimes formed during rough rolling due to reaching the working limits. For duplex stainless steel on which sigma phases (σ phases), which are metallic phases detrimental to processing, deposit at a temperature lower than a certain temperature, stable production is impossible due to decrease of steel material temperature during rolling. Thus, the temperature history during rolling affects the manufacturable range significantly.

2.3 Optimization of the in-line breakdown process

Generally, to produce wire rods and bars, billets with a large section are tapped and then bloomed (rolled). Our wire rod and bar mill uses a high reduction mill (**Fig. 3**) and holding furnace in its in-line breakdown process, and they contribute to the delivery superiority.

High reduction mills can give shearing deformation in addition to compressive deformation that is given by general 2-roll and 3-roll mills. The working limit in shearing is larger than that in compression, in general, and thereby high processing is possible with one high reduction mill. Using effects by the introduction of such shearing deformation more actively may improve the quality. However, since such rolling involves large three-dimensional deformation, quantitative analysis was difficult.

3. Overview of the Problems and Estimated Causes

3.1 Wrinkle defects

To reduce wrinkle defects, compressive strain in the circumferential direction[1] under the current pass conditions was numerically analyzed (**Fig. 4** A)) to obtain indexes for the rolling pass shape and area reduction rate. Conditions of the pass shape and area reduction rate were studied using such indexes and conditions under which compressive strain in the circumferential direction could be significantly reduced were found as shown in Fig. 4 B).

There is a concern about the occurrence of wrinkle defects originating in large grains in ferritic stainless steel, in particular. Higher area reduction in the skew rolling and retention in the immediately

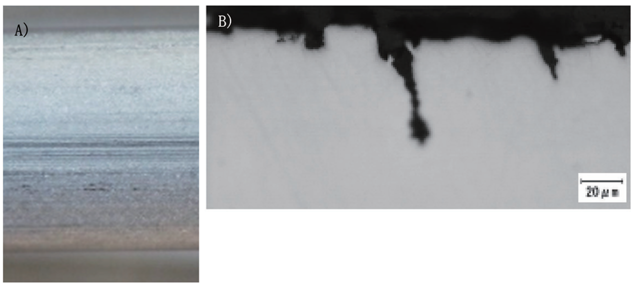

Fig. 2 A) Appearance and B) cross section view of wrinkle defect

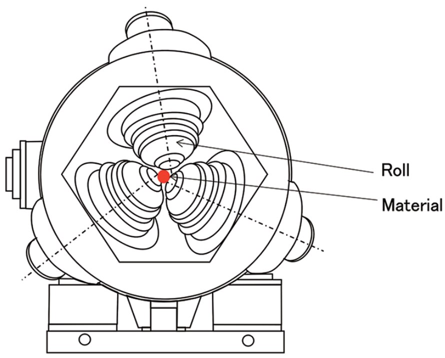

Fig. 3 Overview of high reduction mill (from downstream)

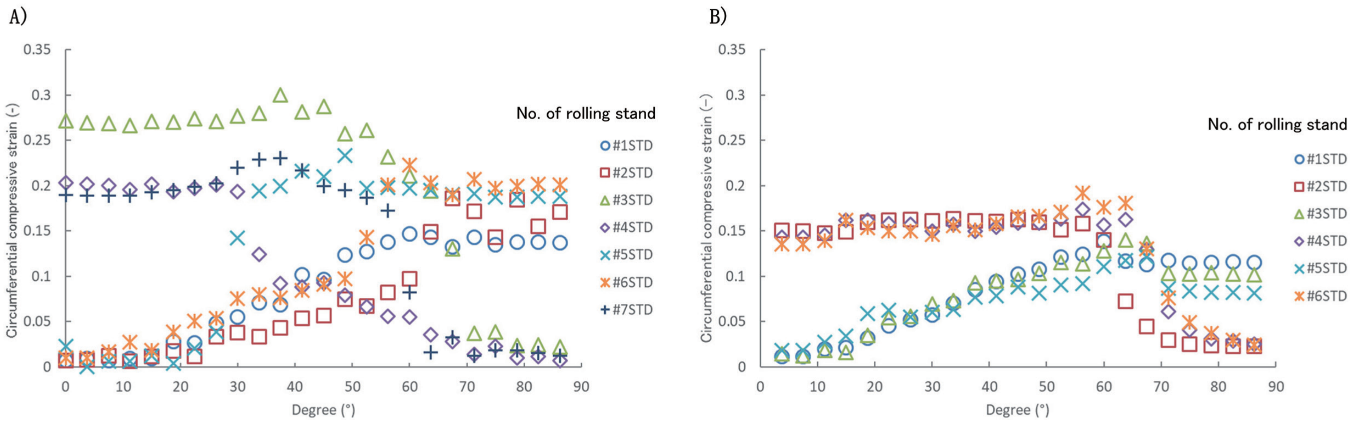

Fig. 4 FEM result of circumferential compressive strain A) before improvement, B) after improvement (Analysis software: NSCARM by Nippon Steel Corp.[2])

following holding furnace may reduce the size of large grains considerably, which may reduce wrinkle defects. This higher area reduction in the skew rolling is described later in Section 3.3.

3.2 Restrictions on the manufacturable range due to temperature decrease during rolling

The temperature of steel materials during rolling is determined by in-process heat generation, natural cooling, and heat abstraction by rolls and other equipment. When the rolling speed is low, heat abstraction exceeds in-process heat generation and thereby the steel material temperature decreases. This tendency is seen in rough rolling. The relationship is reversed in and after intermediate rolling in general, and thereby the rolling temperature increases in those processes (**Fig. 5**). That is to say, suppressing the temperature decrease during rough rolling can raise the rolling temperature range.

The roughing mills that our wire rod and bar mill uses are the horizontal type in which steel materials need to be twisted. The distance between the mills is long to allow steel materials to be twisted. The restriction on the layout may be removed by adopting the horizontal-vertical type.

3.3 Optimization of the in-line breakdown process

The hot workability of steel grades containing sulfur (S) is low due to the deposition of sulfides. Therefore, such steel may crack during rolling. High shearing of the near surface layer in skew rolling may improve the quality. In addition, there is a concern that delta ferrite phases (δ phases) may crack during rolling due to differences in the workability from that of the parent phase. Delta ferrite phases are mainly secondary phases in stainless steel with high content of alloying elements. Therefore, it was difficult for our wire rod and bar mill to produce steel grades with a high ratio of δ phases. Using high shearing deformation that can be given in skew rolling may divide δ phases in steel materials, which may reduce the disadvantage.

To quantify such possibility, the 3D rigid plastic finite element method[3] was used to compare and evaluate the current level and level in the case of higher area reduction. **Figure 6** shows the cross-sectional distribution of equivalent plastic strain in the longitudinal direction of steel materials before and after the improvement. The figure shows large strain on the near surface layers. The figure after the improvement (the rolling reduction was increased) shows that the strain on the near surface layer has penetrated deeply in the radial direction of the steel material and the strain on the near surface layer itself is larger.

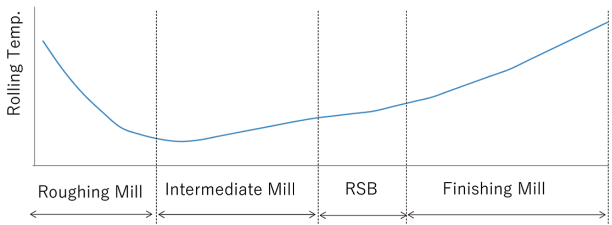

Fig. 5 Image of rolling temperature transition (before improvement)

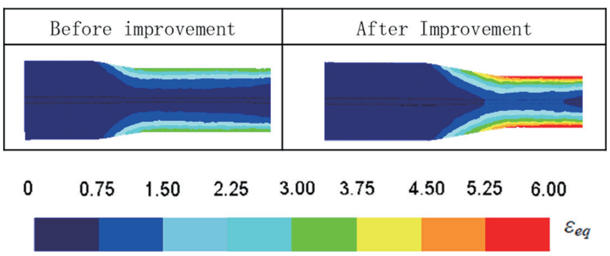

Fig. 6 Equivalent plastic strain distribution

Cracks caused by added S and originating in δ phases can also be reduced through rolling in which the temperature range where the workability is poor is prevented. Therefore, the effect by the raised rolling temperature range described in Section 3.2 can also be expected.

In addition, for ferritic stainless steel described in Section 3.1, the strain to be introduced can be increased by higher area reduction in skew rolling as described above. Therefore, wrinkle defects may also be reduced by making crystal grains finer.

4. Improvement Concept

Based on the results in Chapter 3, the horizontal roughing mills were replaced with horizontal-vertical compact mills and the distance between the stands was shortened to suppress natural cooling. As part of the review of the reduction schedule due to the replacement of the roughing mills, the area reduction rate in the skew rolling was increased, that in the rough rolling was reduced, and the pass shape was reviewed in order to reduce wrinkle defects. The increase in the area reduction rate in the skew rolling was to increase strain to be introduced in order to improve the metallographic structure, aiming at expanding the manufacturable range and improving the quality. In addition, induction heaters were installed between the rolling mills to further suppress the temperature decrease. Furthermore, as a measure to prevent slide marks at the rear end, No. 1 rotary shear was replaced (**Table 1**).

Since the roughing mills are located at the middle section of the rolling line, it was impossible to execute construction in a space separated from the existing work. The construction was divided into some tasks and the construction was repeatedly suspended for a relatively short period of time to prevent continuous operation stop for an extended period of time. The construction was also carried out during operation to maintain a good balance of the construction and production activities.

5. Improvement Results

5.1 Wrinkle defects

Figure 7 shows the changes in the numbers of wrinkle defects in the cross sections of materials in a same steel grade and same size along with their depth. The number of wrinkle defects with a depth of 20 μm or less before the improvement is regarded as 100 for this index. After the improvement, the number of deep wrinkle defects

Table 1 Table of improvement and converted facility

Facility	Content of improvement	Purpose
High reduction mill	Increase reduction	Improve quality Expansion manufacturable range
Holding furnace	Extend temperature holding time	Improve quality
Roughing mill	Replace for horizontal-vertical type Change groove design Decrease reduction	Improve quality Expansion manufacturable range
No. 1 rotary shear	Increase motor capacity Cut speed optimization	Improve quality

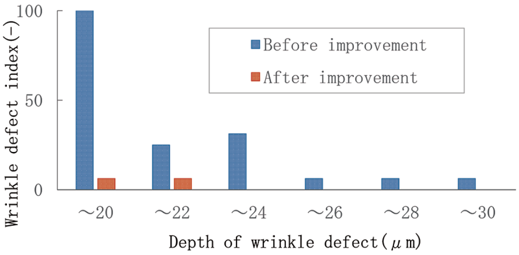

Fig. 7 Histogram of wrinkle defect generation index

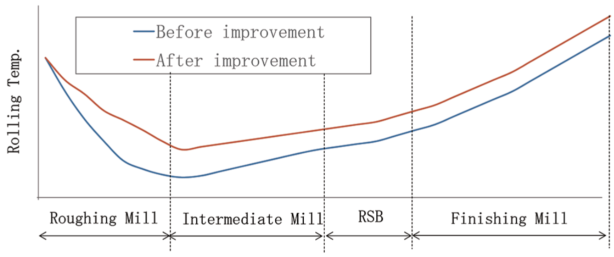

Fig. 8 Image of rolling temperature transition (before and after improvement)

with a depth of 23 μm or more, which are seen before the improvement, becomes zero, and the depth and numbers were reduced generally. However, wrinkle defects with a depth of 22 μm or so still occur. One reason may be because twisting at the intermediate mill remains. In addition, for ferritic stainless steel, the area reduction in the skew rolling was increased, which increased the accumulated strain, accelerating the recrystallization on the near surface layer, which reduced wrinkle defects.

5.2 Restrictions on the manufacturable range due to temperature decrease during rolling

Figure 8 shows the changes in the rolling temperature for φ5.5 before and after the improvement. The improvement could raise the rolling temperature range by 40°C. This improvement has made it possible to roll duplex stainless steel at high temperatures, which makes it possible to prevent a temperature range where σ phases deposit, enabling stable production.

5.3 Optimization of the in-line breakdown process

Higher area reduction in the skew rolling has made it possible to introduce large shearing strain to the near surface layer. Thanks to the combined effect of this improvement and the increase in the steel material temperature described in Section 5.2, austenitic stainless steel grades with a high δ phase rate for hot charging can be manufactured now.

In addition, for steel grades with S added, the higher area reduction in the skew rolling has made it possible to use shearing strain for high processing, which can reduce working cracks.

6. Conclusion

A series of improvements of the rough rolling completed in 2016 has improved the quality and increased the manufacturable steel grades. However, when reviewing the end products, wire rods and bars are only semifinished products. Their quality must be further improved to allow them to be processed to end products and to be used without problems. We will continue improvement in the future as well.

References

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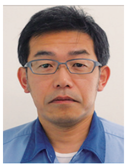
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