Technology

Production Capacity Reinforcement of Duplex Stainless Steel Quarto Plates

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Abstract

Yawata Works of Nippon Steel Stainless Steel Corporation has been engaged in the production of stainless steel plates for 57 years. We have continued to invest in plant and equipment to date, and now our annual production capacity is about 130 000 tons. Since the late 2000s, duplex stainless steel has been used in many fields in order to meet the needs of plant enlargement, diversification of applications, and harsh usage environment. In order to meet the needs of duplex stainless steel plates, we reinforced new equipment and the production capacity of duplex stainless steel plates was increased more than three-fold.

1. Overview

Nippon Steel Stainless Steel Corporation manufactures stainless steel plates at the plate mill in Yawata Works located in Kitakyushu City, Fukuoka Japan. The plate mill was constructed in 1957 at the then Yawata Iron & Steel Co., Ltd. as a state-of-the-art plant for producing regular steel plates. Since then, the mill has been producing regular steel plates mainly for ships and energy and other industries, contributing to Japan's high economic growth. The mill started producing stainless steel plates in 1963, having a history of 57 years.

Through the depression on shipbuilding in the latter half of the 1970s, as regular steel plate production mills in Japan were merged and abolished, our plate mill scaled down the production capacity in 1988, moving toward specialization in stainless steel plates. The annual production scale of stainless steel plates at that time was approximately 40 000 tons and it was gradually increased to 50 000 to 60 000 tons. In 2003, the stainless steel businesses of Nippon Steel Corporation and Sumitomo Metal Industries, Ltd. were merged. The capacity of the conditioning process was increased to meet the increasing demand for stainless steel plates in shipbuilding, energy, IT, and other various industries. The annual production was dramatically increased to approximately 130 000 tons.

Since the latter half of the 2000s, stainless steel plates have been demanded to have various functions and properties following the trend of plant enlargement, diversification of applications, and harsher usage environments. Duplex stainless steel, in particular, has been applied to chemical tankers and desalination plants since it has excellent corrosion resistance (e.g., stress corrosion cracking resistance). Since duplex stainless steel has a more inexpensive alloy composition and higher strength than austenitic steel, it has been applied more widely to various sectors.

In duplex stainless steel plate production, the leveling and pickling capacity in the conditioning process at our plate mill was inferior to that of overseas manufacturers. Therefore, we needed to enhance the capacity to meet the increasing global demand. This report outlines our various measures to increase the duplex stainless steel production implemented for the past several years under such circumstances.

2. Concept of Increase in the Duplex Stainless Steel Plate Production and Overview of the Plan

Duplex stainless steel is a steel grade that features high strength and high corrosion resistance. Since it is extremely strong, loads on equipment in plate leveling after heat treatment are very high. The application of levelers used for conventional austenitic steel plates to duplex stainless steel plate production decreases the throughput due to increase in the number of leveling passes and increases the flatness defect rate due to insufficient leveling capacity. In addition, cutting duplex stainless steel with a shear is difficult due to its high strength and thereby plasma-arc cutting is required. To increase the production, our plasma-arc cutting capacity was insufficient. Furthermore, duplex stainless steel contains a high percentage of Chromium. Therefore, when oxidized scales on the surface formed during hot rolling and heat treatment are descaled in pickling, the processing time per steel plate increases under the same treatment conditions as those for austenitic steel, which reduces the pickling capacity significantly.

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To solve such problems, a state-of-the-art powerful leveler, a new pickling line that would enable high-efficiency pickling, and an additional plasma-arc cutting machine were introduced and the distribution of goods was improved by optimizing the layout of this new line and equipment. These measures have increased the production capacity of duplex stainless steel plates significantly to slightly more than three times that of the conventional level. Among these measures, measures for the leveling and pickling lines that we worked on as priority issues are described below in detail.

3. Overview of the High-strength Cold Leveler

Generally, for stainless steel plates, defects in flatness such as waves and warp formed during hot rolling or heat treatment are cold-leveled to achieve the target flatness. In on-line cold leveling, the mainstream is cold leveling in which a steel plate is passed between leveling rollers arranged in a staggered way to bend the material repeatedly for leveling. However, the maximum leveling force of the existing cold leveler (CL) at our plate mill was only 1 250 tons and the range that could be leveled was narrow. In addition, the material strength of duplex stainless steel is high and thereby the off-line hydraulic pressing process must be combinedly used. When a press leveler is used, small waves tend to remain irregularly and the working efficiency is lower than that when a CL is used. To solve such problems, a then state-of-the-art powerful CL (with a leveling force of 5 000 tons) was introduced.

3.1 Leveling technologies for powerful levers for stainless steel plates

(1) Deformation control

Leveling loads increased due to higher-strength and thickening materials cause the levelers to deform. As shown in **Fig. 1**, deformation components during leveling are divided into two types: Longitudinal deformation that is caused by extension of the leveler housing in the longitudinal direction and transverse deformation that is caused by deformation of the frame and leveling rollers in the width direction. To reduce residual stress in steel plates and obtain good flatness, these two types of deformation need to be appropriately corrected. Regarding the introduced powerful CL, force for longitudinal deformation, a load cell is used to continually measure the leveling force, the correction volume is calculated, and the main reduction cylinders control the position for correction. Meanwhile, for transverse deformation, a sensor installed in the lower section of the CL housing frame measures the deformation volume and the multiple crowning cylinders arranged in the width direction are used for correction. These two types of correction are performed at the same time during leveling to maintain the roll gap at a certain target level, which makes it possible to roll the entire area of a steel plate evenly.

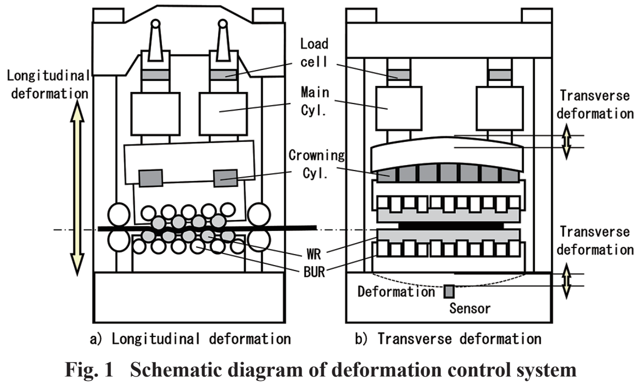


Fig. 1 Schematic diagram of deformation control system

(2) Measures for torque circulation

For a CL, multiple leveling rollers are arranged in a staggered way as its structure. Generally, to level a high-strength steel material, the motor driven torque needs to be increased to the limit by increasing the size of the reduction at the inlet rollers. As a conventional main method, one drive motor is used to drive all the leveling rollers via a gear reducer and distributor as shown in **Fig. 2**(a). However, at the inlet rollers at which the rolling reduction is the maximum, the torque between the rollers change (torque circulation) occurs. If torque circulation exceeds the allowance of the spindle, the spindle may break, which may result in a malfunction and production stop. Therefore, some measures are required, for example, the reduction is limited to prevent excess torque from occurring and a torque limiter is installed between the gear reducer and distributor. In recent years, another method in which a few rollers are grouped and a drive motor is provided for each group is often adopted to reduce torque circulation. In some cases, the individual driving method is adopted in which drive motors in the same number as that of the rollers are used. Since a torque circulation reduction effect was fully expected by introducing a powerful CL for stainless steel plates, the 5-group driving method shown in Fig. 2(b) was adopted considering the maintainability and initial costs of motors, gear reducers, and other components.

(3) Automation of the reduction setting

For our conventional CLs, the reduction is manually set. For stainless steel plates for which a wide variety of products are produced in small batches, the flatness quality often varies due to reduction setting that depends on the skills (feel, intuition, and experience) of operators. To solve such a problem, a new system was created. The system calculates reduction setting data, such as rolling reduction, the number of passes, and processing speed, with an on-line computer based on material information, such as dimensions (thickness and width) and material strength (yield stress) of materials to be processed. It also automatically gives instructions to lower-ranking equipment. This system has made it possible to suppress the influence of differences in the skill levels between operators and to stabilize the flatness quality.

(4) On-line shape measurement technologies

To measure the flatness of materials immediately after leveling quickly and judge if it is acceptable, an on-line shape measurement instrument was introduced at the outlet of the CL. This non-contact shape measurement instrument makes it possible to understand the flatness of an entire steel plate by measuring the height of waves on

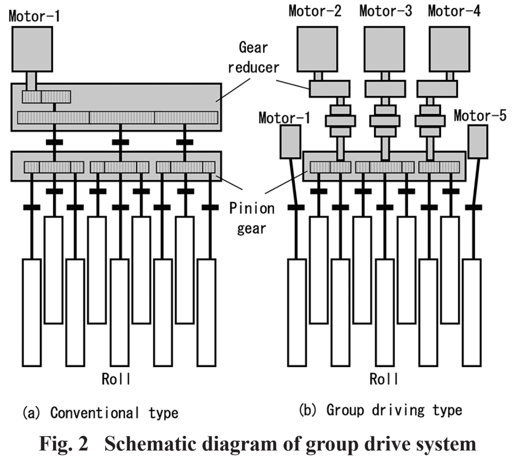


Fig. 2 Schematic diagram of group drive system

the steel plate with laser beams. **Figure 3** shows example flatness measured with the on-line shape measurement instrument. The measuring instrument allows operators to understand the flatness after the leveling instantly. If a defect in the shape remains, the shape can be corrected by setting additional pass(es) and adjusting the reduction finely. Therefore, this instrument has been significantly reducing reprocessing from the final inspection process, contributing to improving the production flaws in the entire plant enormously.

3.2 Effects by the introduced CL

The introduced powerful CL has significantly improved the flatness after the leveling. **Figure 4** shows the measured flatness for 40-mm-thick SUS304 plates. Before the powerful CL was introduced, press leveling was performed to level that size of materials. On the conventionally press-leveled material, many small waves are left and the shape improvement effect remains approximately half of that before the leveling. On the other hand, for the plate that was processed with the powerful leveler, the flatness was remarkably improved. In addition, decreased residual stress considerably suppresses shape changes when customers recut plates (e.g., in bar steel cutting), contributing to improving the customer satisfaction levels greatly.

4. Overview of the High-efficiency Pickling Line

The corrosion resistance of duplex stainless steel is higher than that of general-purpose stainless steel. Optimum continuous pickling conditions were tested and evaluated at our laboratory to determine line specifications (including safety and environment measures) and line layout.

4.1 Acid solution conditions

Under acid solution conditions for general-purpose austenitic stainless steel, the pickling time required to descale duplex stainless steel (equivalent to SUS329J3L) is several ten times that for SUS 304 and other similar grades. Therefore, the descaling characteristics of duplex stainless steel were studied at our laboratory based on acid composition and temperature. Then optimum pickling conditions and line specifications were determined in consideration of acid resistance and heat resistance conditions and costs of materials used for the pickling line. Finally, the pickling line established in this measure was used to process test pieces in various grades under various pickling conditions to evaluate the quality in order to determine regular pickling conditions.

4.2 Pickling line configuration

Figure 5 illustrates the line configuration. As improvements from the conventional pickling line, the following three points are described below: (1) Materials for the pickling tank and other tanks, (2) improved drive section of the transportation table, and (3) concentration management of iron in acid solutions.

(1) Selection of acid-resistant materials for the pickling tank and other tanks

For pickling lines, measures to prevent acid solutions from leaking when the linings are separated are considered. For the applied high-concentration acid solution, measures to prevent problems caused by separation of the lining are required more than before. Therefore, the thickness of the carbon-fiber reinforced plastic (CFRP) layer in the lining inside the tank was increased compared to the conventional one for reinforcement. In addition, as the shell of the pickling tank, duplex stainless steel was used. Even if part of the lining is separated or deteriorated and the acid solution penetrates into the tank shell, the duplex stainless steel does not immediately erode unlike regular steel. Therefore, the safety at the time of line inspection can be secured and initial actions when the acid solution leaks can be smoothly conducted. In addition, for the pickling circulation tank, polypropylene with excellent acid resistance and heat retaining properties was used.

(2) Improved drive section of the transportation table

As a measure to prevent the acid solution from leaking from the transportation table roller drive section inside the pickling tank, a three-stage labyrinth structure was adopted for the inside in place of the conventional two-stage labyrinth structure also in consideration of the maintainability. On the outside, a double V-ring sealing structure with a higher sealing property was adopted in place of a single rubber seal to enhance the liquid sealing property significantly (**Fig. 6**).

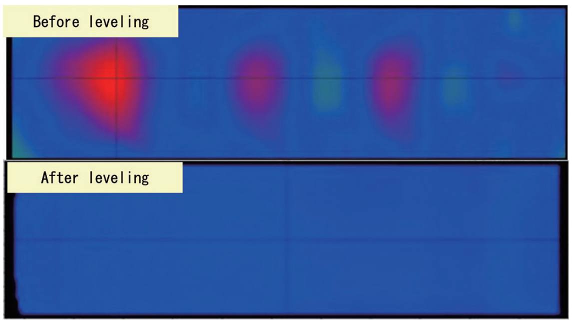


Fig. 3 Measurement results by flatness gauge (ex. thickness: 40 mm, stainless steel plate)

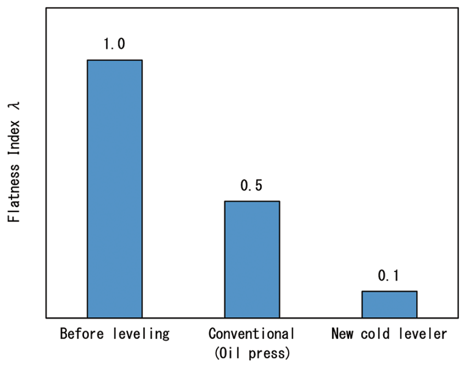


Fig. 4 Effect of new cold leveler (ex. thickness: 40 mm, stainless steel plate)

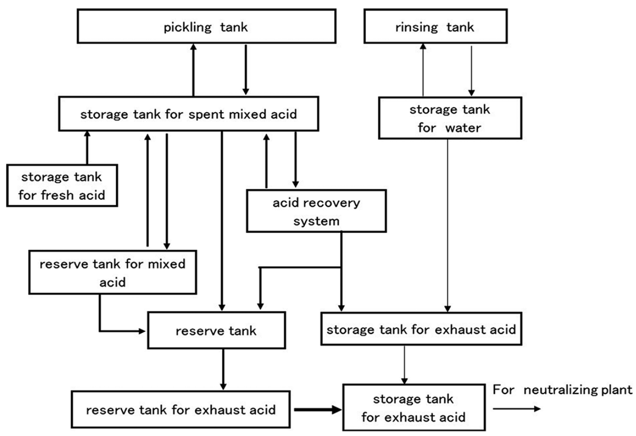
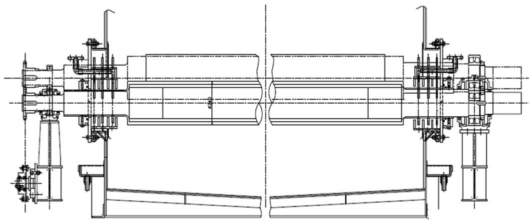
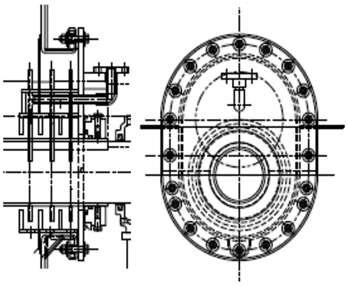


Fig. 5 Flow chart of pickling line



a) Cross section of pickling tank



b) Labyrinth seal

Fig. 6 Cross section of pickling tank and labyrinth seal

(3) Concentration management of iron in acid solutions

The higher the concentration of iron in an acid solution is, the lower the flame scarfing capability. The relationship between iron concentration under the high-concentration pickling conditions to be applied and descaling properties was studied at our laboratory to select an optimum management value. In addition, a new iron remover with the ion exchange resin method was adopted in place of the conventional ion exchange diffusion membrane method to enhance the heat resistance and acid recovery efficiency and reduce the running cost.

4.3 Configuration of environment-friendly acid discharge equipment

Since high-concentration acid solutions are used on the new pickling line, the waste acid management was also reviewed. To make it possible to immediately tackle an accident, a moderate acid solution tank was installed before the weak acid solution tank to lower the concentration. A buffering configuration was established by adding a spare tank to the waste acid collection place from the conventional pickling line at the plate mill so that solutions could be

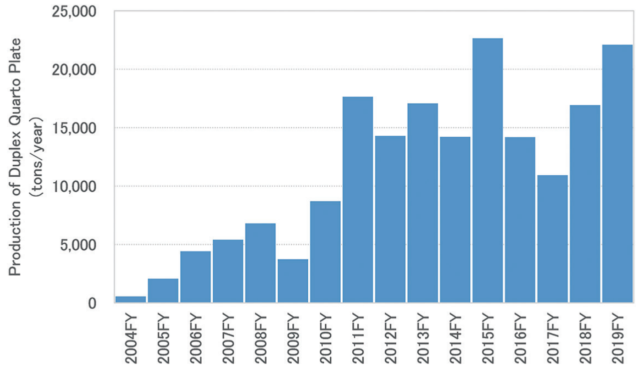


Fig. 7 Statistics of duplex quarto plates in Yawata Works

accumulated even in an emergency. In addition, an automatic nitrogen measuring device was introduced to measure and monitor the concentration of nitrate nitrogen in waste acid continuously. If an abnormality is found, the discharge of the waste acid can be immediately stopped to prevent environmental accidents.

4.4 Effects by the introduced line

The introduced high-efficiency pickling line improved the pickling efficiency significantly, which has made it possible to dramatically increase the production of duplex stainless steel plates for which pickling is difficult. We have confirmed that this line can pickle high-alloy stainless steel plates efficiently in addition to duplex stainless steel plates. This line can also contribute to the expansion of our product lineup in the future.

5. Summary

The construction was completed and the operation began in August 2010. The line and equipment have been operating smoothly since then. As shown in the changes in the duplex stainless steel plate production in **Fig. 7**, the production has been increasing and we have been able to meet strong demand. Recently, more upward flexibility has been secured by improving the operation conditions and taking other measures to meet the demand exceeding the conventional plan. We will consider equipment so that we can meet the demand for steel materials for harsher environments and upgrade the manufacturing base as the main plant to manufacture wide high-alloy special steel plates in addition to stainless steel.

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