Introduction of Image-Based Inspection System to Deformed Steel Bar

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Linear defects are a common surface defect in deformed steel bars. Due to their extremely narrow width, they have conventionally been difficult to detect through visual inspection. In the use of deformed bars as structural components, one method of connection involves pressure welding. Linear defects can lead to cracking at the upset joint during pressure welding, posing a significant obstacle to productivity in downstream processing. This report presents the implementation of a defect detection system in the production line with high-intensity lighting and high-resolution imaging that enables the reliable detection of linear defects and prevents the outflow of defective products.

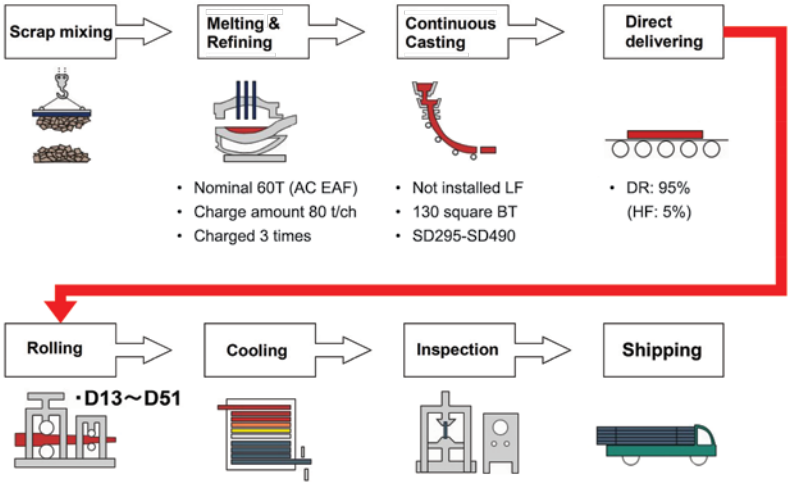
Introduction

Tokai Co. Ltd.'s manufacturing process is as follows. The electric furnace is a nominal 60-ton alternating current furnace. After tapping, the molten steel is transported directly to the continuous casting process producing 130-mm-square billets. The deformed steel bars produced by the facility conform to JIS G 3112 (steel bars for concrete reinforcement), covering strength grades from SD295 to SD490. In the rolling process, deformed steel bars are produced in sizes from D13 to D51, also in accordance with the JIS standard. Furthermore, Tokai Co. Ltd. employs an integrated direct rolling process, which streamlines the entire production flow from steelmaking to rolling, ensuring high production efficiency.

Inspection systems are installed within the rolling process to detect defects. Nonconforming products are subsequently removed from the line based on the inspection results.

Figure 1

Tokai Co. Ltd. manufacturing process.



However, the conventional system has inherent limitations in its detection capability, and certain surface defects could not be properly identified. Consequently, defective materials occasionally passed through the process and were inadvertently shipped to customers (Fig. 2).

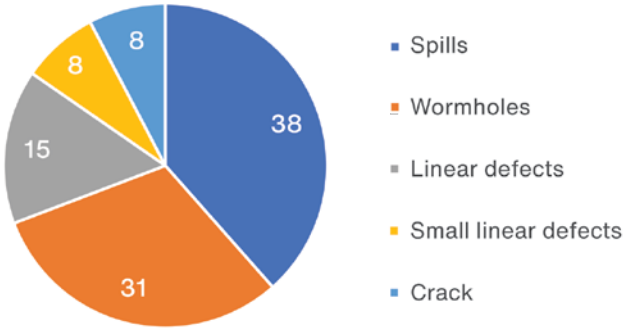
An eddy current flaw detector was used. In principle, it is difficult to detect linear defects or defects with gradual changes. Additionally, noise caused by the ribs of deformed steel bars can cause large scabs (Fig. 3) to be overlooked, which constitutes a significant challenge.

To suppress defect occurrence in rolling products, measures were implemented in the steelmaking process, including revisions of Δt management, adjustments to mold cooling capacity and the frequency of mold maintenance. Additionally, to address linear defects (Fig. 4) in the rolling process, roll calibers and rolling guide components were modified, and the rolling loop control conditions were changed. As a result, the occurrence of defects has been reduced, though they have not been completely eliminated.

This report presents the implementation of a defect detection system on the production line with high-intensity lighting and high-resolution imaging, along with improvements to identified issues and the imaging conditions.

Figure 2

Breakdowns of complaint items (%), 2015–2022.



Comparison of Flaw Detection Methods

Eddy Current Flaw Detector: In 2010, the plant adopted an eddy current flaw detector for deformed steel bars. Eddy current flaw detectors use a self-induction method, in which the excitation coil and the detection coil are the same. When rolled steel is penetrated in the magnetic field generated by passing an alternating

Figure 3

Example of a scab.



Figure 4

Example of a linear defect.



Figure 5

Eddy current flaw detector detection principle.

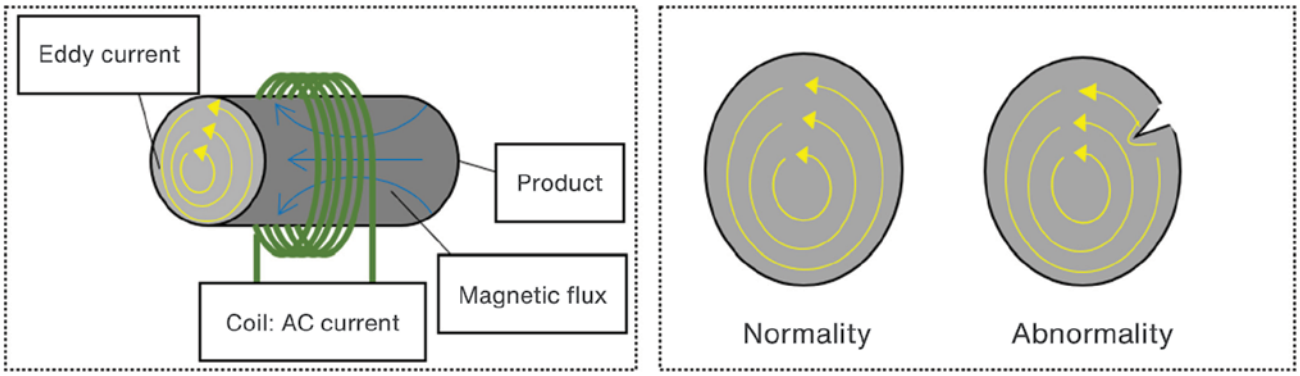


Figure 6

Quality complaints (left: foreign object defect, right: wormhole).





current through the coil, eddy currents are generated (Fig. 5). The eddy current changes due to defects or cracks in rolled steel, causing the impedance to increase or decrease. This is amplified to produce a defect signal. Two coils are installed and compared to detect defects. To detect defects, the clearance between the coil and the rolled steel must be set within a strict range. It was difficult to resolve issues such as overdetection and false detection, and sufficient detection accuracy could not be achieved, ultimately resulting in defective products being shipped the outside (Figs. 6 and 7).

Thermal Imaging Flaw Detector: Thermal imaging flaw detectors are a flaw detection method that has become widespread in recent years. The thermal imaging method of inspecting defects in hot steel involves measuring the brightness distribution of red-hot steel with a line sensor. The resulting brightness image is then analyzed to detect defects on the steel. That is, defects such as cracks and scabs on rolled steel cause changes in the brightness image, and this method detects such defects by measuring these changes with a line sensor camera.[1] Brightness is correlated with temperature, and the surface temperature of the flawed part of a deformed steel bar is lower than that of the normal part. This creates a difference in brightness, making it possible to detect defects. As a result, it boasts extremely high detection performance for scabs.

However, if the resistance during transport causes the scab to peel off and expose the inside, the temperature change is small, and even large defects may not be detectable in principle. This is a significant disadvantage: the inability to detect defects that have a significant effect on mechanical property. The detector has limitations. The system is unable to detect linear defects with narrow openings. As the image captures the thermal imaging of the hot steel, only a vague outline is obtained (Fig. 8). It is difficult to make a final judgment by visually inspecting the detected image. Therefore, operators must either visually inspect the product before bundling or remove the product without visual inspection.

Figure 7

Quality complaint (nodular cracks occurring due to pressure-welded linear defect).



Reflected Light Image Flaw Detector: Methods similar to that of the reflected light image flaw detector were experimented. However, practical application in rolling has not yet progressed. The reflected light image flaw detector irradiates red-hot steel with visible light that is brighter than thermal radiation by the steel

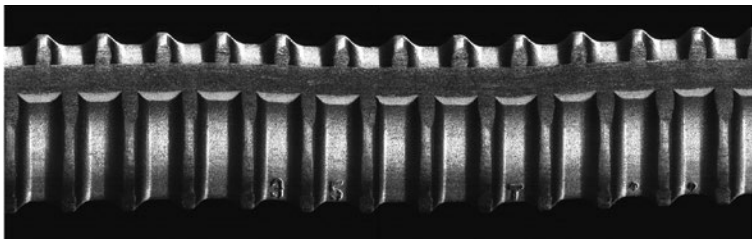
Figure 8

Image captured by thermal radiation image flaw detector.



Figure 9

Image captured by reflected light image flaw detector.



itself. Consequently, it creates a product image by stacking captured at high speed by a line sensor camera. The detector uses thresholds for the defect area and number in the image, as well as a machine-learned judgment system, to identify defects. The image of the hot steel, taken at approximately 1,000°C, is a high-resolution image, similar to that seen with the naked eye when viewing cold steel (Fig. 9). As a result, it is possible to determine whether false positives are based on the image alone, eliminating the need for visual inspection of the actual product. Furthermore, it is theoretically possible to detect linear defects of 0.1 mm or less, which are difficult to detect using eddy current flaw detectors or thermal imaging flaw detectors (Figs. 10 and 11); for example, scabs and wormholes are possible to detect because they certainly have a clear difference in brightness.

Comparison of Detector Methods: The following section presents a summary of the flaw detector accuracy and features in the deformed bars production (Table 1).

Figure 10

Linear defects (below 0.1 mm).

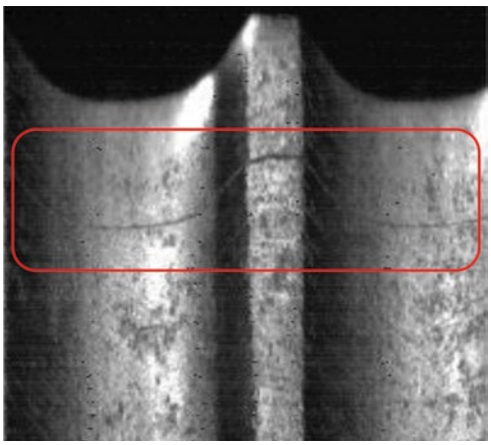


Figure 11

Linear defects (approximately 0.1 mm).

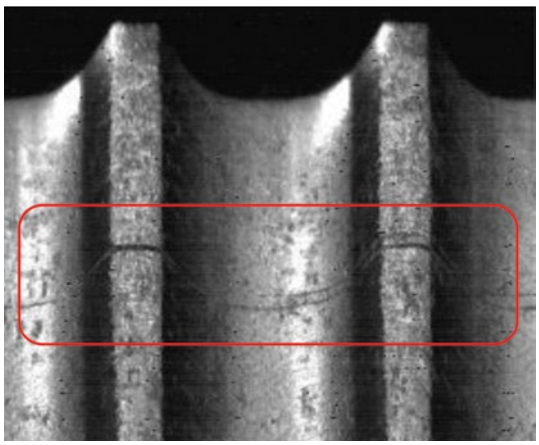


Table 1

The Flaw Detector Accuracy and Features

	Scabs	Wormholes	Linear defects	Remarks
Eddy current flaw detectors	△	△	×	The specific shape and speed of deformed steel bars affect detection accuracy
Thermal imaging flaw detectors	○	△	△	Small changes in brightness are difficult to detect
Reflected light image flaw detectors	○	○	○	High-intensity light creates a clear contrast between light and dark, resulting in high resolution

Figure 12

Equipment layout.

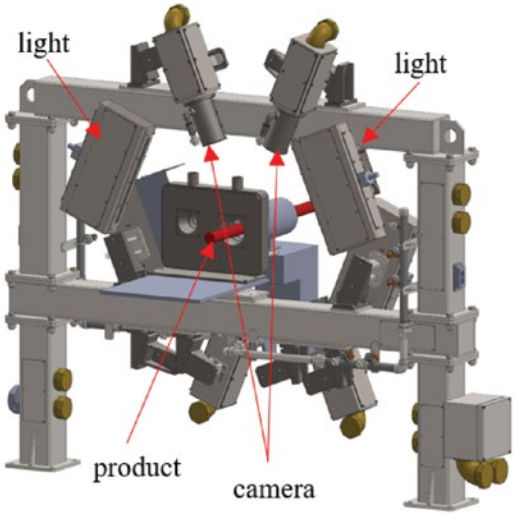
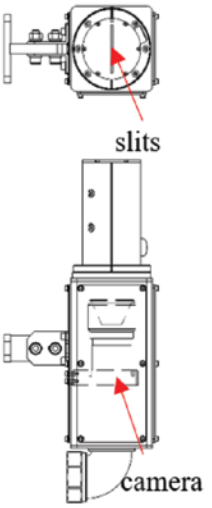


Figure 13

Camera case.



Installation of Reflected Light Image Flaw Detector

Equipment Layout: The layout of equipment for the reflected light imaging flaw detector is illustrated in Fig. 12. It was installed after the dividing shear because detecting as-roll products after they are divided improves the accuracy of defect position. Cameras were installed in four directions and lighting was installed in four directions so that it could be irradiated from both sides of the cameras because it detects the entire circumference of the product. The upper and lower cameras are positioned out of phase to avoid interfering with the angle of view. To prevent dust from entering and adhering on the cameras and lights, a dustproof camera case with slits (Fig. 13) and a purge air device were installed.

Tracking System: Fig. 14 shows the rolling mill layout. After hot rolling, intermediate and finishing, the steel is cut to the cooling bed length by the dividing shear and delivered to the cooling bed. After the steel is cooled, it is cut to the specified length using a cold shear and inspected on the inspection line. After inspection, it is bundled in the specified number and a tag is attached. The authors have developed a tracking system that allows operators to remove defects detected by the reflected light image flaw detector on the inspection line.

The tracking system screens are installed in four locations within the mill: rolling quality control room, cold shear operation room, measurement instruction room and inspection line.

Tracked defective products are inspected on the inspection line. Workers can check images of defects on the tracking system screen (Fig. 15), improving work efficiency.

Results

Initial Problems

1. Reduction in brightness due to scale getting into the camera case. Scale entered the lower camera case and adhered to the camera lens surface, reducing brightness (Fig. 16).
2. False positives due to reflection of scale or water when capturing images. Roll scale and roll cooling water were brought into the knot of the deformed steel bar, and these were captured in the imaging area, resulting in false positives (Fig. 17).

Figure 14

Rolling mill layout.

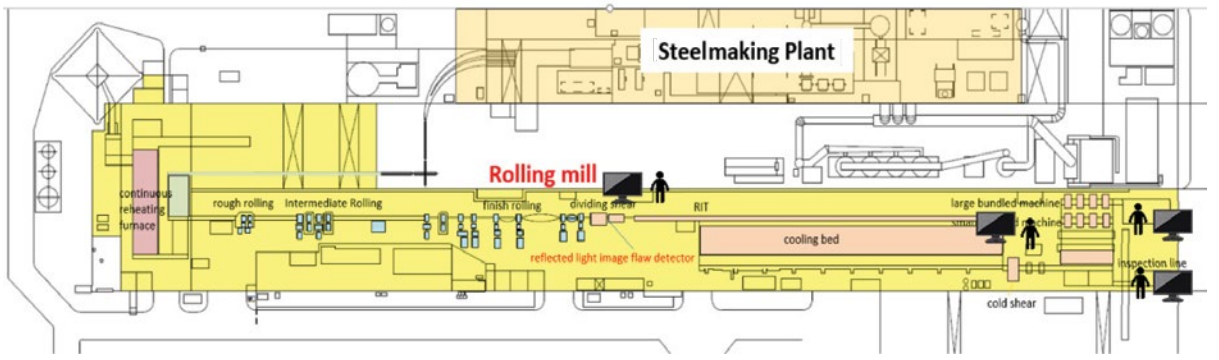
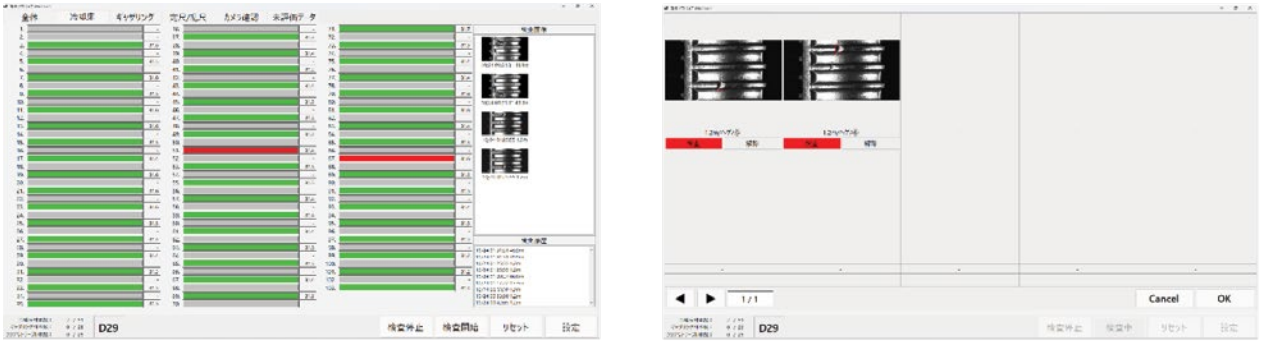


Figure 15

Tracking system screen.



3. False positives due to oblique images. In case steel is passed through the imaging range while moving left or right, the image will appear to show the product meandering diagonally because a line scan camera is used. As a result, the rib position fluctuated in the direction of travel, resulting in false positives (Fig. 18).

Countermeasures for Initial Problems

1. Reduction in brightness due to scale getting into the camera case. Scale intrusion was reduced by installing gaskets, relocating the purge air and adjusting the air flowrate.

Figure 16

Inside the camera case.

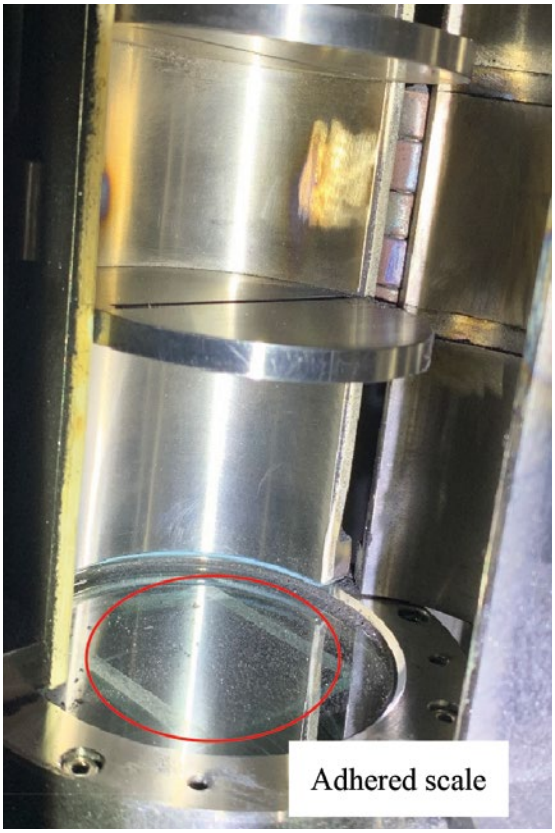


Figure 17

Image capture (reflection of water).

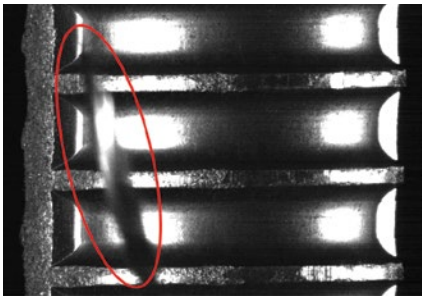


Figure 18

Image capture (oblique image).



2. False positives due to reflection of scale or water when capturing images. By installing an air purge and protective plates, the reflection of scale and water in the imaging area was reduced.
3. False positives due to oblique images. The outline of the steel bar was extracted from the difference between the background (low brightness) and the deformed steel bar (high brightness),

Figure 19

Scab defects.

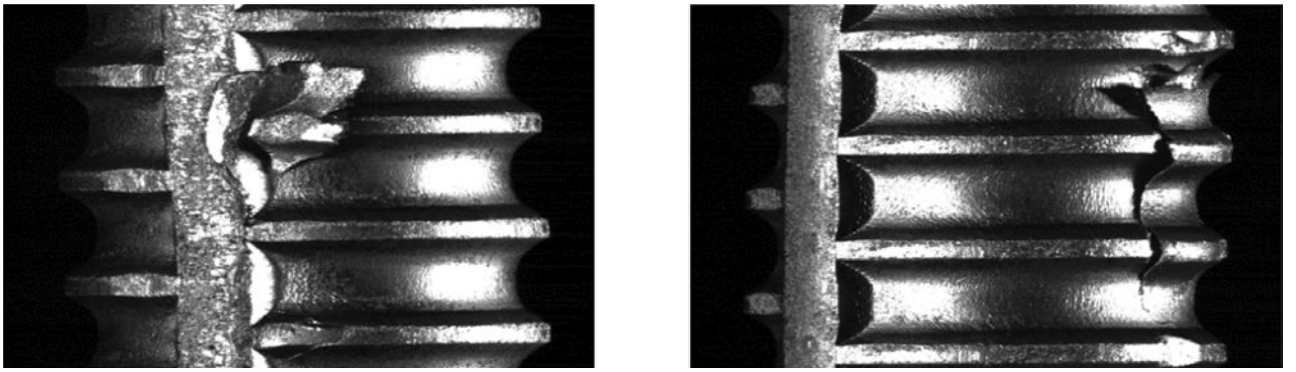


Figure 20

Wormholes.

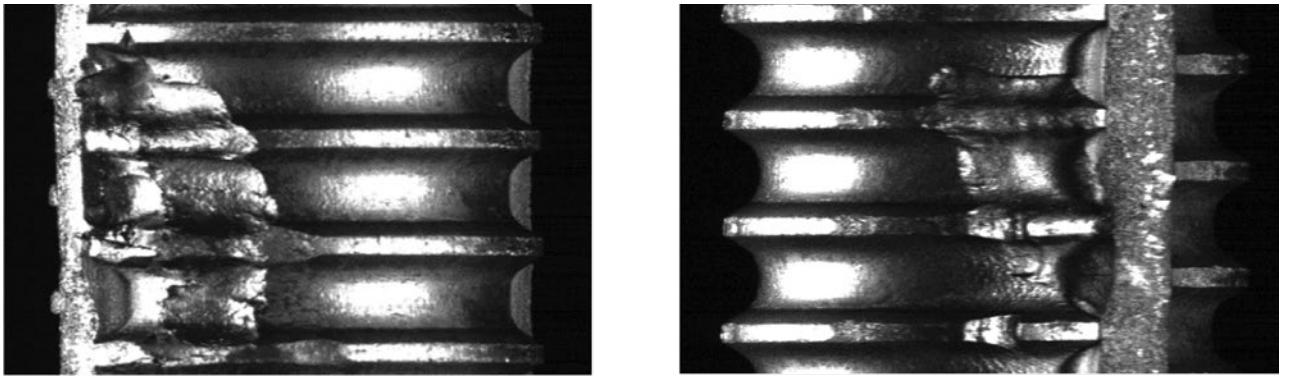


Figure 21

Linear defects.

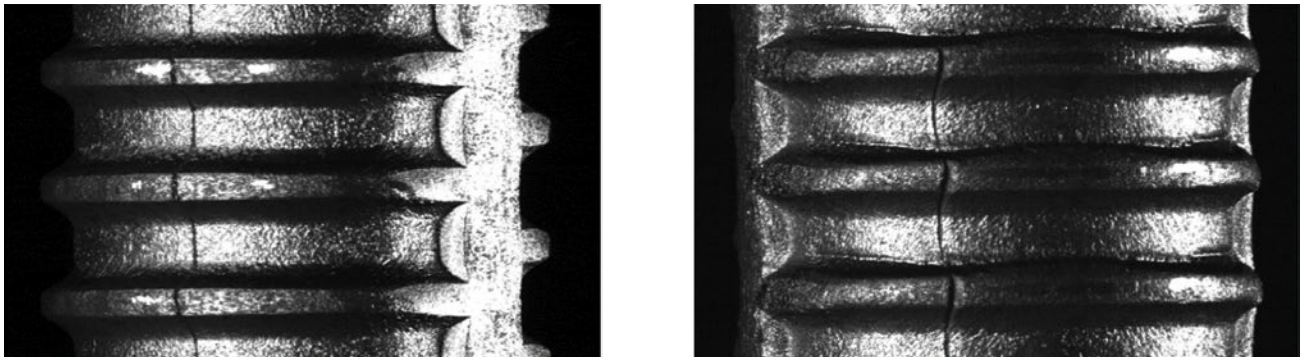
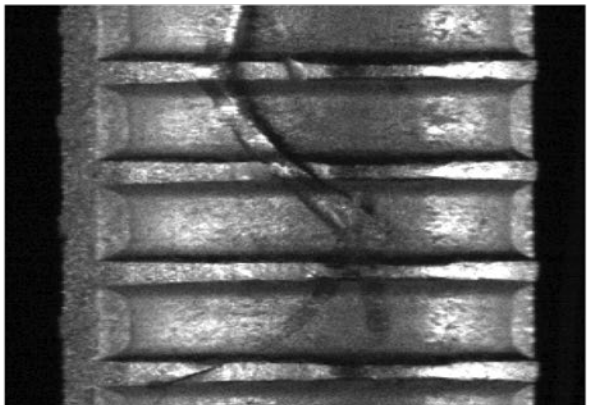


Figure 22

Other defects.





and the coordinates of the base, circle, and node sections in the direction of travel were corrected to be straight.

Defect Detection Status: After resolving the initial problems, it became possible to detect various surface defects, as follows:

1. Scabs (Fig. 19).
2. Wormholes (Fig. 20).
3. Linear defects (Fig. 21).
4. Others (Fig. 22).

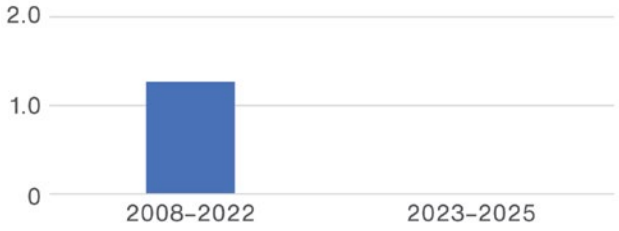
Effects of Implementation

Fig. 23 shows the index of complaints due to defects from 2008 to 2025.

After the installation of the reflected light image flaw detector, complaints about rolling defects were eliminated to zero per year from 2023 onwards.

Figure 23

Defect Complaint Index (cases/100,000 tons).



Conclusions

This report describes an attempt to use a reflected light imaging flaw detector to detect linear defects in hot-rolled deformed steel bars, which are difficult to detect using conventional detection methods due to their extremely small width.

In addition to scabs and wormholes, it became possible to detect linear defects of approximately 0.1 mm in size, preventing the outflow of surface defects.

This article is available online at AIST.org for 30 days following publication.

Reference

1. MSK Japan Co. Ltd., "Inspection Method and Device for Surface Defects in Hot Steel Products," JP 2013-036850 A, 2013.

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