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Development of Inspection System for Tiny Scales on Stainless Steel Sheets after Pickling†

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Abstract:

In Stainless Steel Plant, East Japan Works (Chiba), JFE Steel, scale on the surface of hot-rolled stainless steel sheets is removed in pickling process after annealing. Inspection of the scale remained on steel sheet surface is very important. Since the scale defect is very small, the operators had to stop the line for manual inspection. However, the inspection area was limited, and the line speed had to be lowered. In order to improve these problems, JFE Steel has developed inspection system for tiny scales on stainless steel sheets after pickling.

1. Introduction

Stainless steel sheets are shipped to customers or to the downstream process through a manufacturing process which comprises annealing of hot-rolled steel strips, removal of the scale remaining on the strip surface by pickling, and an inspection section. If scale removal in this process is inadequate, there is a possibility that tiny scales may remain on the strip surface. If the product is rolled further in this condition, this scale defect will cause conspicuous defects on the surface. Therefore, JFE Steel developed an "Inspection System for Tiny Scales." The following introduces the measurement method and inspection performance of the developed system.

2. Inspection of Remaining Scale

Figure 1 shows the stainless steel manufacturing process. In a stainless steel plant, scale on the surface of steel strips is removed by shot blasting or pickling. However, if trouble in the operating equipment or other abnormal conditions occur, there is a high possibility that scale will remain on the strip surface. The appearance of the scale defect is shown in **Photo 1**. The results of an investigation of the characteristics of this remaining scale defect by optical microscopy revealed that the scale defect consists of a band of tiny black spots on the order of 0.1 mm within 1 mm.

Although a surface inspection system[1)] is installed in the inspection section at the delivery side of the line, detection of scale defects is not possible because the optical configuration is designed to detect defects such as scabs and scratches, and its optical resolution is inadequate to detect tiny remaining scales. Accordingly,

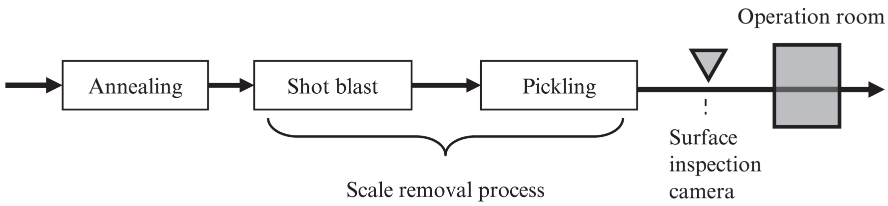

Fig. 1 Stainless steel manufacturing process

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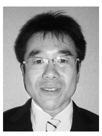

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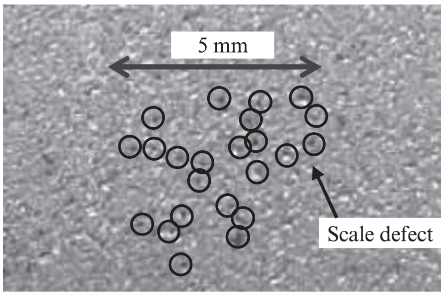


Photo 1 Example of the scale defect

Photo 2 Inspection of scale defect

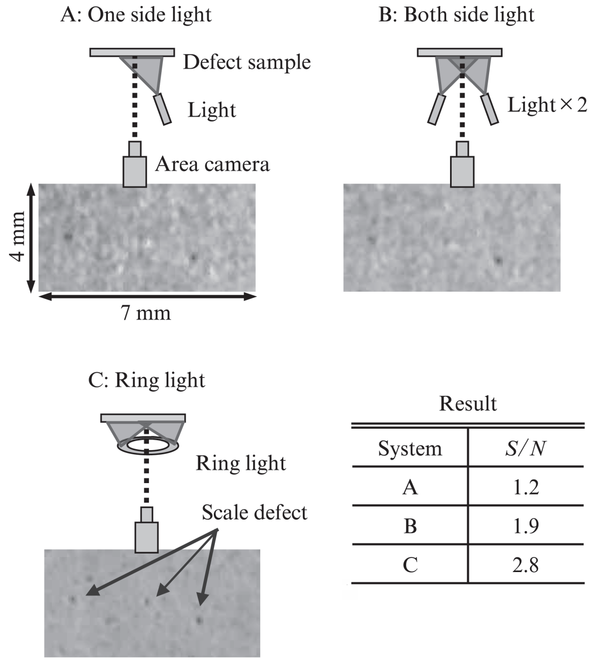
inspections for scale defects are performed by operation of room operators by stopping the line periodically and performing manual inspections (visual inspections with a magnifier), as shown in **Photo 2**, but in any case, the inspection range is limited. Moreover, since the full length of the strip cannot be inspected, it is necessary to operate under excessive descaling conditions on the low-speed side in order to prevent scale defects completely.

To improve quality by enhancing the level of appearance inspections and to stabilize operation, JFE Steel began the development of a specialized inspection system for inspection of tiny remaining scales.

3. Scale Defect Inspection System

3.1 Selection of Optical Configuration

A high resolution imaging device is necessary in order to detect remaining scale with a size of 0.1 mm. Furthermore, because the surface of stainless steel strips, which are the object of inspection, do not have uniform characteristics and shot marks remain on the surface, there is a high possibility of multiple detection (over-detection) of background noise with the general optical configuration applied in inspection systems, making practical inspection difficult. Based on these facts, JFE Steel studied an optical configuration that would be suitable for inspection of tiny remaining scales.



Result

System	S/N
A	1.2
B	1.9
C	2.8

Fig. 2 Results of scale defect imaging tests

Multiple scale defect samples were collected, and imaging tests of these samples were conducted with many types of optical configurations by changing the inspection lighting and irradiation method and the specifications of the camera. An example of the test results is shown in **Fig. 2**. Scale defects can be detected by optical configurations A and B in the figure. However, because the shadows of surface irregularities are also imaged as black spots in the same manner as scale defects, S/N, is low (S/N: Ratio of defect signal S to background noise N). On the other hand, with configuration C, in which a ring light is used for lighting and the center of the lighting is photographed by the camera, the surface was irradiated from multiple directions making it possible to cancel out the shadows of shot marks and other surface irregularities. As a result, scale defects could be clearly distinguished from the background, and a high S/N was obtained.

3.2 Improvement of Inspection Lighting

The products manufactured at Stainless Steel Plant, East Japan Works (Chiba), JFE Steel include many types, one of which is high quality mirror surface products. Although a standard ring light was used in the imaging test described above, cases in which the S/N of scale defects was reduced when inspecting mirror surface products were discovered, as shown in **Fig. 3**. As the cause of this problem, in mirror surface products, the bright field component is strong, as surface roughness is small and specularity is high in comparison with other products. It was estimated that detection of scale defects is difficult because part of this bright field is photo-

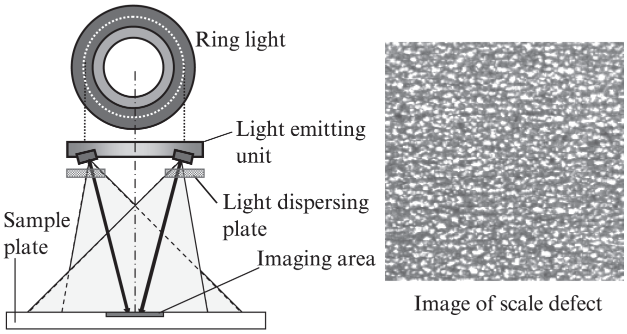


Fig. 3 Result of scale defect imaging tests applying standard ring light unit

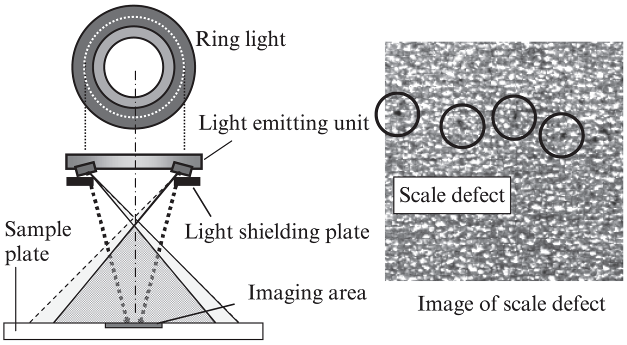


Fig. 4 Result of scale defect imaging tests applying improved ring light unit

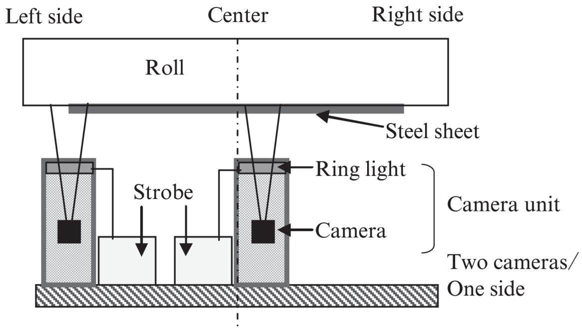


Fig. 5 Detecting unit

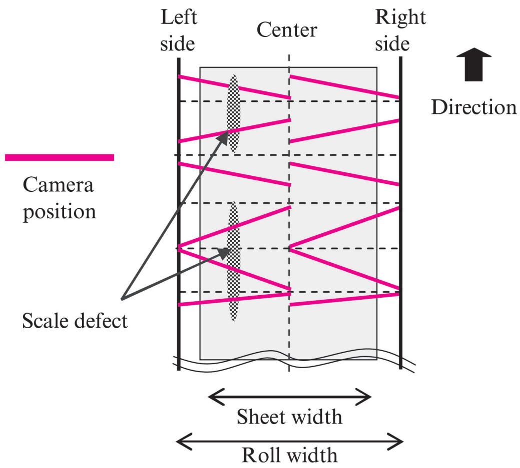


Fig. 6 Inspection area on steel sheet

graphed by the camera, increasing background noise.

As a result of a study of an optical configuration which enables detection of scale defects even in mirror surface products, the method shown in **Fig. 4** was found to be effective. This device is configured so that the camera view above the steel sheet is a perfect dark field by attaching a ring-shaped light shielding plate to the light-emitting part of the ring light. The shield plate used here is an aluminum ring which was treated by black almite treatment, and completely cuts off light. It was confirmed that this prevents the bright field component from reaching the camera and thereby improves the *S*/*N* of scale defects. However, since the light of the ring light is shielded in this method, reduction of lighting intensity is a drawback. Compared with the general ring light in Fig. 3, the intensity of the light received by the camera is reduced to 1/8 to 1/10. The lighting intensity necessary for inspections was secured by adopting a high intensity strobe light.

3.3 Configuration of Detection Section

An inspection unit for introduction in the actual equipment was produced based on the optical configuration developed in Section 3.2. **Figure 5** shows the configuration of the actual detecting unit, and **Fig. 6** shows the detection range on the product.

In this inspection system, it is necessary to secure inspection resolution on the order of 0.03 mm by narrowing the field of view of the camera, but this means the distance between the camera and the inspection surface is shortened to approximately 100 mm. When the system was initially introduced, full length and full width inspection of the steel sheet surface was studied, but to realize this, more than 40 cameras would be required in the strip width direction. As a distinctive feature of the scale defect, this defect occurs continuously over a long time at the same width position in the strip travel direction. Therefore, two cameras are arranged on each side of the strip, and the cameras are scanned in the strip width direction at a constant speed.

4. Online Evaluation

4.1 Results of Scale Defect Detection

After introduction of the actual scale defect inspection system, detection performance was confirmed by comparison with the results of manual (visual) inspections. An example of the inspection results is shown in **Fig. 7**. The horizontal axis in this figure is time (= Sheet measurement length), and the vertical axis is the number of pixels of the scale defect detected by the inspection

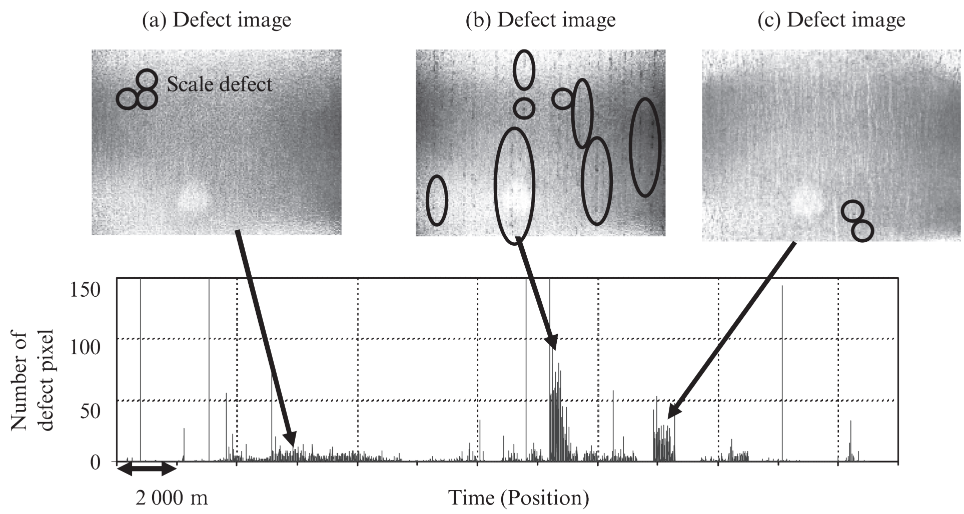


Fig. 7 Example for result of inspection

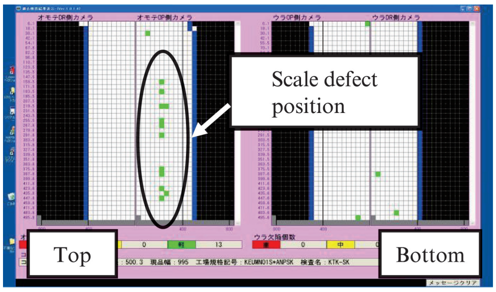


Fig. 8 Inspection display

system. A large number of defect pixels indicates that there many scale defects in the image, as shown in (b) Defect image. Two methods were used to verify inspection performance : (1) In case the inspection system detected a scale defect, the line was stopped, a manual inspection was performed, and the results were compared. (2) In case a scale defect was discovered by conventional manual inspection, this result was compared with the condition of detection by the inspection system. A thorough comparison of the inspection system and manual inspection was conducted, and it was found that the inspection system detected 100% of the defects discovered by manual inspection. This study also confirmed that the inspection system detected defects that could not be discovered by the operators. These results confirmed that the specification of the developed system is sufficient for a specialized inspection system for scale defects, even when using the method shown in Fig. 6.

The condition of inspection is displayed in map form in real time, as shown in **Fig. 8**. It can be understood that scale defects are being detected continuously in the length direction at the same transverse position on the top side of the steel strip. In case of serious defects, in which the defect area in one image is large, the map display changes (concretely, light defects are shown in green and serious defects in red), and the system makes an announcement to the operators. In this way, a quantitative display of the distribution of occurrence of scale defects is possible over the entire strip. This level of information was not possible with the conventional manual inspection method.

4.2 Control of Inspection Performance

In order to guarantee that the Automatic Surface Inspection System functions normally, it is important to establish a daily inspection method. In daily inspections, it is desirable that simple inspections are possible during operation, and quantitative control is also possible. The following presents a daily inspection method that satisfies these conditions. This method was introduced in the actual inspection system.

In this system, a test piece for performance verification is built into the camera unit. When performing daily inspections, this test piece is photographed, and the average gray and number of black pixels obtained as a result of that imaging are controlled in order to confirm inspection performance. In test pieces, black points with a size of φ 0.2 mm are imprinted on a piece of white glass. These test pieces are installed in all 4 camera units. During daily inspections, the test pieces are photographed and images like that shown in **Photo 3** are acquired. The right side of the figure shows a 12 pixels × 12 pixels enlargement of a φ 0.2 mm black spot. Next, within the range of the test shown in the figure, the number of pixels and the average gray value exceeding the inspection threshold are calculated, and the results are displayed on the inspection unit screen.

As daily inspection results, the average gray and number of black pixels are displayed for the total of 4 cameras, as shown in **Table 1**. The value of average gray gradually decreases due to various causes such as aged

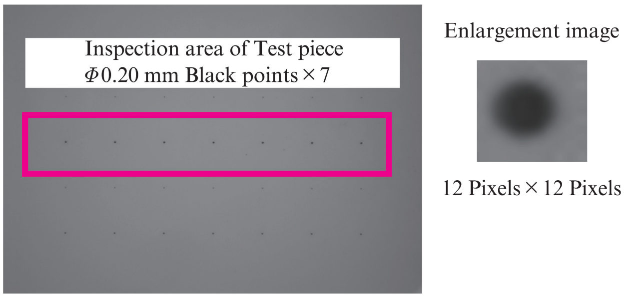


Photo 3 Image of test piece

Table 1 Result of inspecting test piece

	Camera 1	Camera 2	Camera 3	Camera 4
Average gray	90.6	94.0	93.2	85.0
Black pixel	174	191	182	178

deterioration of the strobe lamp, dirt on the camera lens and the like. Since the detection level of detectable black spots decreases accompanying the decrease in average gray, the number of black pixels also decreases.

In addition, the number of black pixels also decreases when camera abnormalities, defocusing or other abnormalities occur. Although the values are not the same due to hardware-related differences in the cameras and lighting, it is possible to grasp the advance signs and trends of abnormalities by controlling the respective values for each camera unit.

In carrying out a daily inspection, the inspection is started by button operation. The series of actions comprising retraction of the camera, setting of the test piece, imaging, and display of the inspection results is then performed automatically, and the inspection is completed in a short time of approximately 20 seconds. At present, daily inspections are performed at a frequency of once per day, and the numerical values of average gray and the number of black pixels are recorded and controlled. Control values and limit values are set for these numerical values. An alarm is output when the results fall below the control value, and inspection and maintenance are performed before reaching the limit value. Moreover, the lamp exchange and periodic maintenance cycles are determined by long-term control of these data, thus realizing stable, long-term operation of the inspection system.

5. Conclusion

An inspection system which is capable of detecting tiny remaining scales on stainless steel strips was developed by adopting an optical configuration using a ring light and an equipment composition in which the cameras are scanned in the strip width direction. This inspection system is currently in operation at Stainless Steel Plant, East Japan Works (Chiba), JFE Steel and is making an important contribution to quality assurance of products.

References

1) Sasaki, Toshihiro; Takada, Hideki; Tomura, Yasuo. JFE Technical Report. 2007, no. 9, p. 60–63.