Development of Welding Condition Monitoring System in Cold Steel Sheet Process Line

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Abstract:

The continuous annealing line for cold rolled steel sheets is a process in which steel sheets are continuously annealed by welding the preceding and following sheets with a welding machine at the entry section. When sheet fracture occurs due to defective welding, operation stops, and restoration work takes a long time. Therefore, technique to stable welding and a device to detect weld defects with high accuracy are required for stable operation. We have developed a 2D thermometer to precisely measure the temperature of the weld zone and a weld monitoring device at the continuous annealing line of JFE Steel East Japan Works (Chiba).

1. Introduction

The layout of the continuous annealing line (CAL) for tin plate at JFE Steel's East Japan Work (Chiba District) is shown in **Fig. 1**. In this process, steel sheets are annealed continuously by welding the preceding and following sheets with a welding machine[1)] at the entry section. Since sheet fracture due to defective welding results in an operation stop and requires considerable time for restoration work, a technique for ensuring normal welding and a device for detection of welding defects with high accuracy are required. Although a system for judging welding quality by measuring the temperature of the weld had been used, judgment performance was a problem. Therefore, to achieve higher judgment accuracy, a 2D thermometer which measures the weld profile temperature and a welding condition monitoring system were developed.

2. Welding at Continuous Process Lines

Figure 2 shows a schematic diagram of seam welding by the welding machine (mash seam welding machine) at the CAL entry section. At the welding machine, welding conditions are set based on specifications such as the steel type, sheet thickness, etc. of the preceding and following sheets. The tail end of the preceding sheet and the head end of the following sheet are lapped, and the upper and lower welding electrode rings are applied to the sheets at the set pressure. When the set welding current is passed in this compressed condition, the surfaces in contact with the electrode rings are heated, and the preceding and following sheets are welded by melting and solidification from the sheet surface. Welding of the full width of the sheet is then completed by running the electrode rings in the

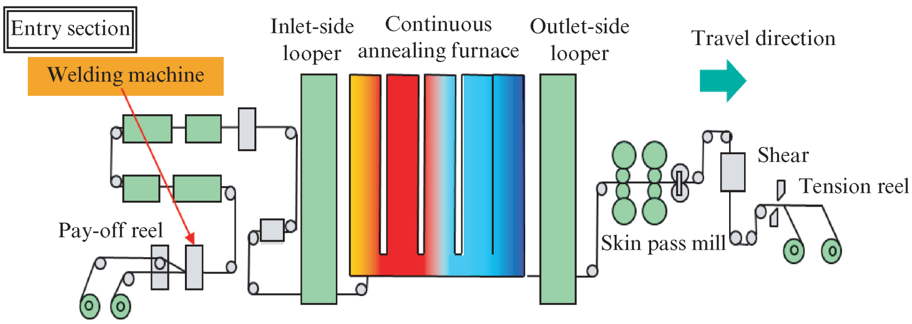

Fig. 1 Layout of continuous annealing line

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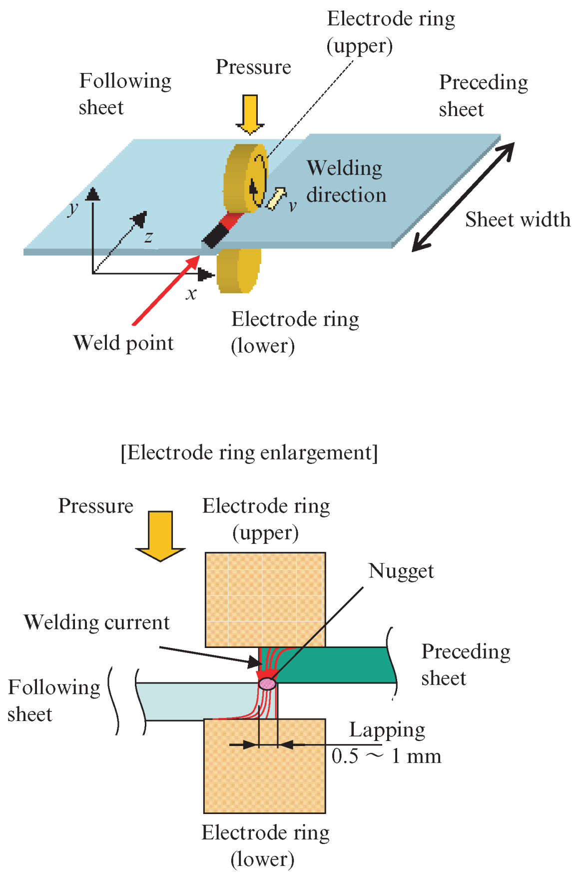

Fig. 2 Schematic diagram of seam welding

width direction. Normal welding is achieved when welding is performed at the proper welding current and electrode force[2)].

However, if the electrode force of the electrode rings is lower than the set value due to an equipment abnormality, expulsion of molten metal from the weld and nugget crack (a welding defect) will occur. This is one cause of welded sheet fracture. Since expulsion of the molten metal from the sheet surface increases temperature variations in the weld during nugget crack, measurement of the weld temperature is an effective method for judging normal and abnormal welds. Therefore, a technique of measuring the weld temperature with an auxiliary radiation thermometer on the welding machine and judging the weld quality from the measured temperature has been used since an early date. Weld quality judgment based on the weld temperature is also applied to welding machines at continuous annealing lines at JFE Steel.

3. Welding Temperature Measurement

In welding machines at continuous annealing lines, the welding temperature immediately after welding is measured by a spot-type radiation thermometer installed after the travel direction of the electrode ring.

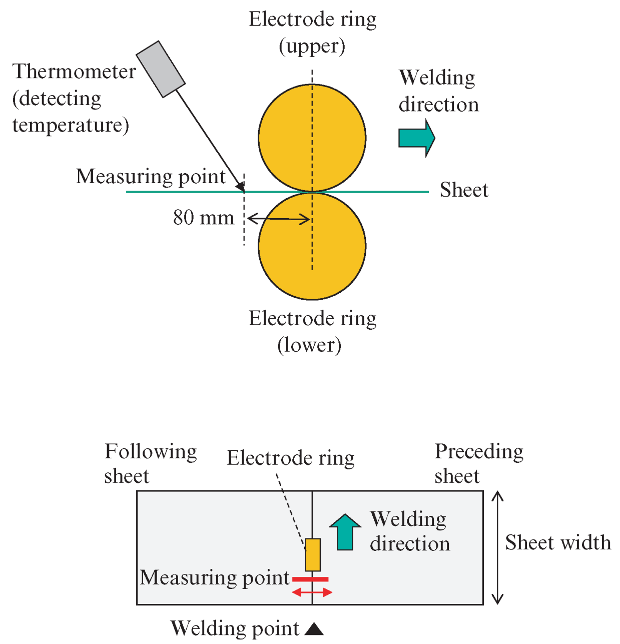

Fig. 3 Temperature measurement positions

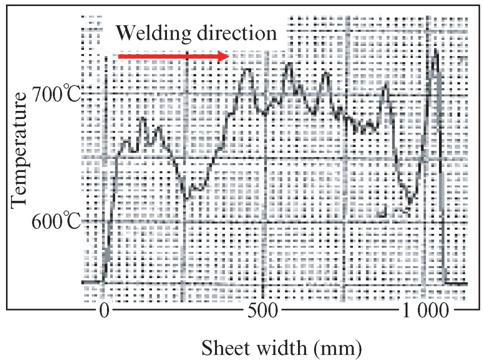

Fig. 4 Welding temperature measurement

Figure 3 shows the measuring point of the radiation thermometer, and **Fig. 4** shows an example of the welding temperature measurement results. At the tin plate line, the performance of the welding quality judgment device was relatively low compared to the same device at the automotive steel sheet line. When the welding temperature measurement results and welding quality judgment results of the two devices were compared, the cause of this problem was considered to be the unsuitability of the device for judging the welding quality as welding temperature measurements are unstable with the tin plate products.

Therefore, the cause of unstable temperature measurement values was verified. In tin plate for can-making and steel sheets for automotive applications, the steel type and size of the product are different (**Table 1**). In a welding machine, welding is performed after setting the proper lap allowance and welding conditions such as the welding current, etc. according to

Table 1　Sheet size for automobiles and tin plate

	Automotive sheet	Tin plate
Thickness (mm)	0.40 — 2.60	0.15 — 0.60
Width (mm)	800 — 1 900	600 — 1 200

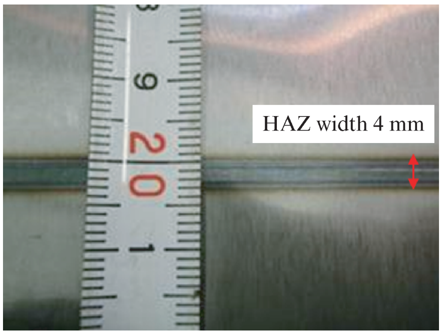

Photo 1　Appearance of welding steel sheet

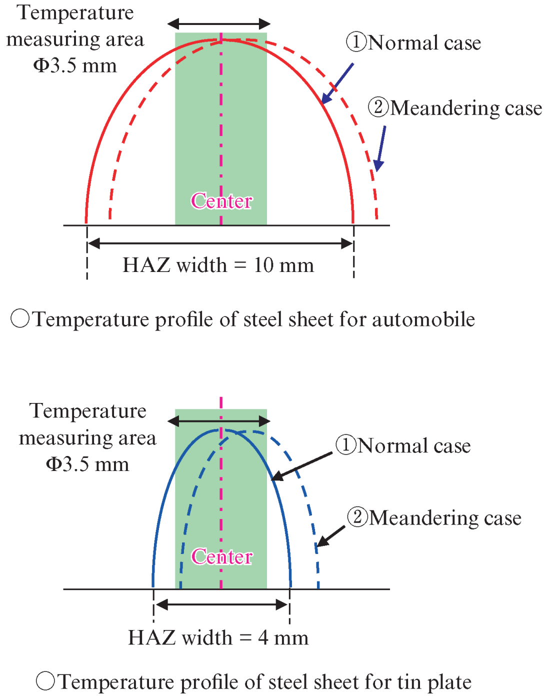

Fig. 5　Temperature profile of welding steel sheet

the object of welding. When welding automotive sheets, the lap and welding current are larger because the product sheet thickness is thicker than that of tin plate, and a larger amount of heat is necessary in welding. As a result, the weld temperature is also higher. **Photo 1** shows an example of the appearance of the HAZ (Heat-Affected Zone) of the preceding and following sheets after heating and welding.

Although the HAZ width of automotive steel sheets after completion of normal welding is approximately 10 mm, the HAZ width of tin plate is about 4 mm. To check the size and temperature of the HAZ during welding, the temperature of the HAZ was measured by installing a test scanning-type radiation thermometer in addition to the conventional spot-type radiation thermometer. **Figure 5** shows schematic illustrations of the temperature profiles of the welding HAZ of an automotive steel sheet and tin plate, respectively.

The measurement area of the spot-type radiation thermometer (measuring field of view: φ3.5 mm) is aligned with the center of the HAZ. Because the 4 mm width of the HAZ of tin plate is close to the 3.5 mm measuring field of view of the thermometer, the area where the temperature profile changes abruptly is measured. This means the values measured by the thermometer are easily affected by the accuracy of the thermometer setting position, fluctuations in the HAZ width and meandering of the steel strip (when meandering occurs, the temperature profile changes from ① to ② in the figure).

In welding of automotive sheets, the range of the high temperature area from the weld centerline is wide. Therefore, the measured values are stable and are relatively unaffected the thermometer setting accuracy and meandering of the HAZ, which were problems in welding temperature measurements of tin plate. The measured values of a spot radiation thermometer will be more stable if the detection range is wide, but changes will be smaller and more difficult to detect, which is an obstacle to welding quality judgment.

Based on the results described above, an effective welding thermometer and condition monitoring system for the cold rolling process were developed for welding temperature measurement of tin plate.

4. Development of Welding Thermometer

A welding thermometer was developed to achieve highly accurate welding quality judgments in welding of tin plate. **Table 2** shows the development items, purpose and requirements for the thermometer, and **Fig. 6** shows the composition of the detection unit of the developed thermometer. There were two development items, ① Smaller size of the detection unit and ② Wide range of the measuring field of view and temperature profile. First, the reason why a small-size detection unit is necessary is explained. The area around the welding electrode rings contains a dense arrangement of devices, and the space available for installation of the detection unit is limited. On the other hand, if the thermometer can be installed near the electrode ring, the distance to the weld (measurement point) is short, and the HAZ of the weld can be measured with high resolution. Therefore, a small thermometer that allows

Table 2 Development items and requirements for thermometer

Development item	Purpose	Requirements
Small size of detection unit	Mount in close to electrode rings a) To achieve a high resolution b) To measure the temperature immediately after welding	Size: Detection unit Φ30 mm ＊ 200 mm or less
Wide range of measurement profile (2D)	a) Measurement of HAZ width b) To follow the weld meandering c) Response to inadequate thermometer installation	Measuring field of view: 20 mm or more Resolution: 0.2 mm or less

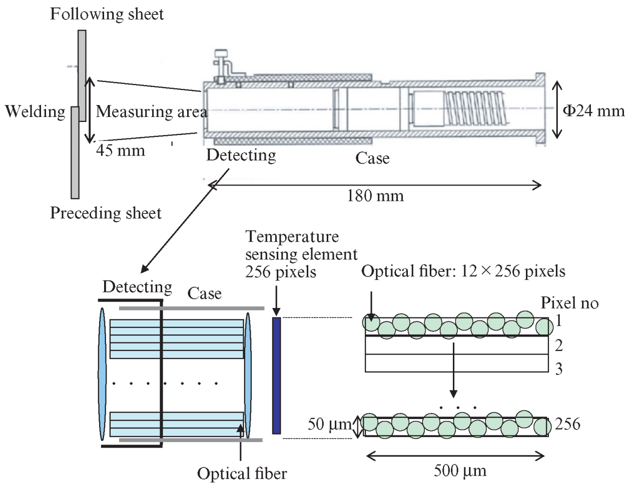

Fig. 6 Composition of thermometer

installation near the electrode ring was adopted as a development target. Next, the composition of the thermometer is explained in Fig. 6. For measurement of the temperature profile, in the detecting part of the thermometer, a 256-pixel sensing element was arranged perpendicular to the traveling direction of the welding machine to enable measurement of the width profile of the HAZ temperature. The detection unit comprises a lens that focuses the infrared light from the weld (measurement target), and a sensing element that receives the infrared light via multiple optical fibers. As a result of study and design, a thermometer with a diameter of Φ24 mm and length of 180 mm, which satisfies the requirements (diameter: Φ30 mm and length: 200 mm or less), and is capable of measuring a temperature profile of 45 mm was fabricated.

The developed thermometer was installed near the welding electrode ring. In trial operation after installation, a measuring field of view of approximately 45 mm and temperature profile resolution of 0.17 mm were confirmed, satisfying the requirements (measuring field of view: 20 mm or more, temperature profile resolution: 0.20 mm or less). Since the developed thermometer also measures the temperature profile of the HAZ, it is referred to as the "2D (dimension) thermometer" in the following.

5. Results of Welding Temperature Measurement and Quality Judgment

Examples of the measurement results of the actual 2D thermometer are shown in Fig. 7 and Fig. 8. In order to acquire temperature data in the HAZ width direction in each scan of the temperature sensor, the 2D thermometer totals the measured data for the HAZ width direction and the welding direction after welding is complete and displays a temperature map, as shown in Fig. 7. Fig. 8 shows an enlarged view of part of the temperature map, together with a schematic of the sensor scans and temperature data in the HAZ width direction, that is, the temperature profile. The graph on the left shows the measurement points (1) to (10) on the temperature map, and the graph on the right shows 10 temperature profiles for each of the scans. As can be seen in this graph, the HAZ width and peak temperature position change in each of the 10 temperature profiles, and among the 10 profiles, the HAZ width decreases by about 40% in comparison with the other profiles only in Scan No. (5).

Based on the measured data acquired with the 2D thermometer, the conditions for welding quality judgments were studied. Although temperature measure-

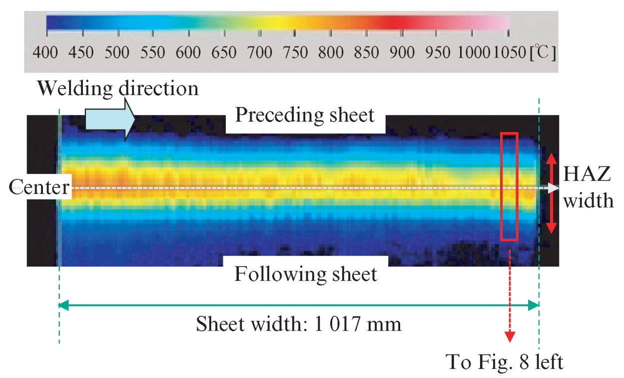

Fig. 7 Welding temperature measurement result / temperature map

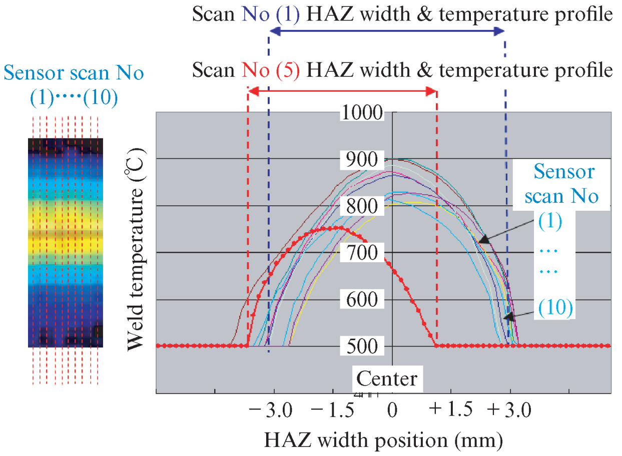

Fig. 8 Welding temperature measurement result / Temperature profile per sensor scan

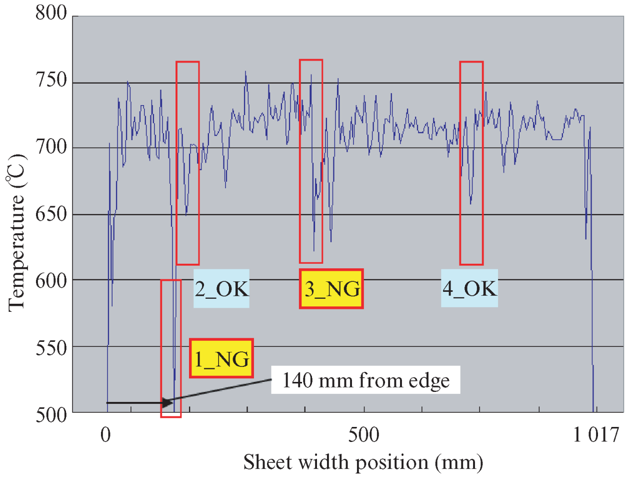

Fig. 9 Result of welding temperature (sheet width position)

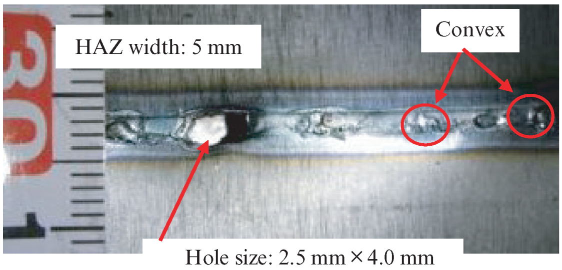

Photo 2 Appearance of welding defect

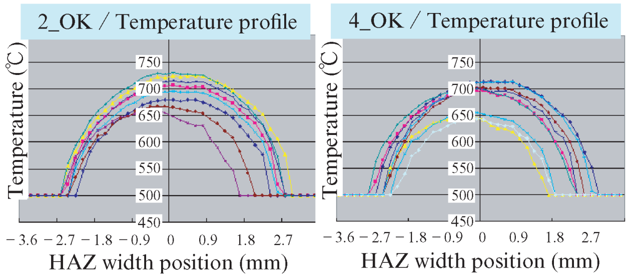

Fig. 10 Result of welding temperature (normal temperature weld profile)

ment data for welding which is judged to fail are necessary, the frequency of welding failures in actual operation is low. Therefore, in this study, the necessary data were acquired by performing welding tests, in which welding failure was intentionally caused by performing welding with an overcurrent with the welding current set 30% higher than in normal operation, and the weld appearance was compared against the welding temperature data. **Photo 2** shows the appearance of a welding defect acquired in the welding test, and **Figs. 9**, **10** and **11** show the welding temperature measurement results. The appearance of the weld defect indicated that protruding convex parts and a hole due to nugget cracking occurred locally.

In the temperature chart for the sheet width direction (i.e., welding direction) in Fig. 9, the four sheet width positions where temperature drop occurred compared with the actual weld. Among the four temperature drop positions, the weld appearance was normal at the two positions indicated by 2_OK and 4_OK in the figure. The 10-point temperature profiles at these two positions are shown in Fig. 10. The appearance of 1_NG and 3_NG showed that holes had occurred in both cases. Fig. 11 shows the 10-point temperature profiles and weld appearance at these positions. At 1_NG, the defect could be detected easily, since the welding temperature was less than 500°C, which is the lower limit of measurement by the thermometer, and in comparison with normal parts, the temperature difference was large. On the other hand, it was difficult to detect the defect at 3_NG because the temperature was similar to that of other areas where temperature drops occurred. However, judgment of the defect is possible by using the temperature profile information. For example, a defect can be detected at 3_NG because the temperature profile of 3_NG contains a part where the minimum HAZ width is only 3 mm, whereas HAZ width of normal areas is 5 to 6 mm. With traditional spot-type radiation thermometers, it was possible to obtain measured temperature data only for the strip width direction. In contrast, with the 2D thermometer, changes in the HAZ width and welding temperature peak positions before and after defects, etc. can be understood from the temperature profile data.

A logic for judgment of welding abnormalities was constructed by judging the possibility of detecting various types of weld defects by applying the strip width temperature and temperature profile, repeatedly conducting welding tests, and collecting examples of weld defects, and a welding defect judgment system was

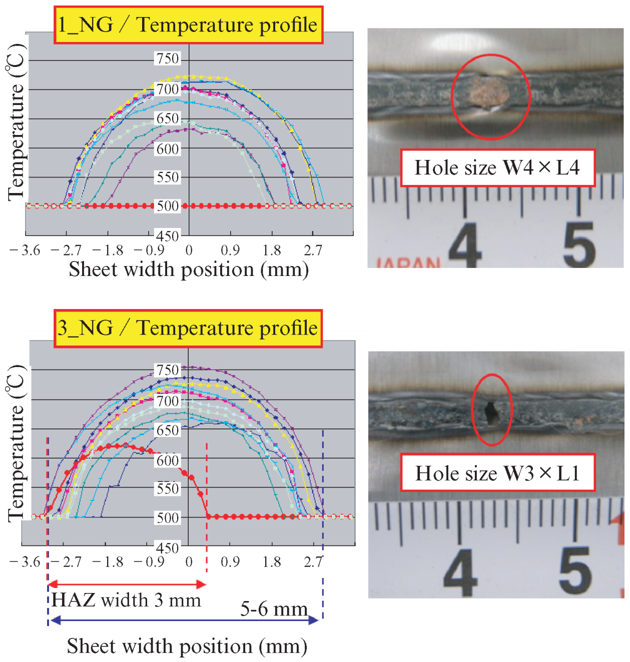

Fig. 11 Result of welding temperature (abnormal temperature weld profile)

implemented. An example of the welding quality judgment logic is shown in **Fig. 12**. The judgment logic is explained in the following.

Judgment 1 (Judge 1): Monitoring exceedance of the temperature lower limit threshold

Conventional judgment method; simple judgment as abnormal is made when a welding temperature lower than the set threshold occurs.

Judgment 2 (Judge 2): Monitoring of heating range in strip width

Heating range (%) = Width exceeding the threshold (mm) / Strip width * 100

The heating range in the strip width is calculated, and the weld is judged to be abnormal when the heating range is less than the set value.

Judgment 3 (Judge 3): Monitoring of HAZ width

The HAZ width is calculated for each acquired temperature profile, and the weld is judged to be abnormal when the HAZ width is less than the set value.

Judgment 4 (Judge 4): Monitoring of heating centerline position

The HAZ centerline position, defined as the temperature peak position, is calculated for each acquired temperature profile, as in Judgement 3. Following this, the amount of variation (1.7 mm in the figure) of the HAZ centerline position and the actual center position is calculated, and the weld is judged to be abnormal when the amount of variation exceeds the set value.

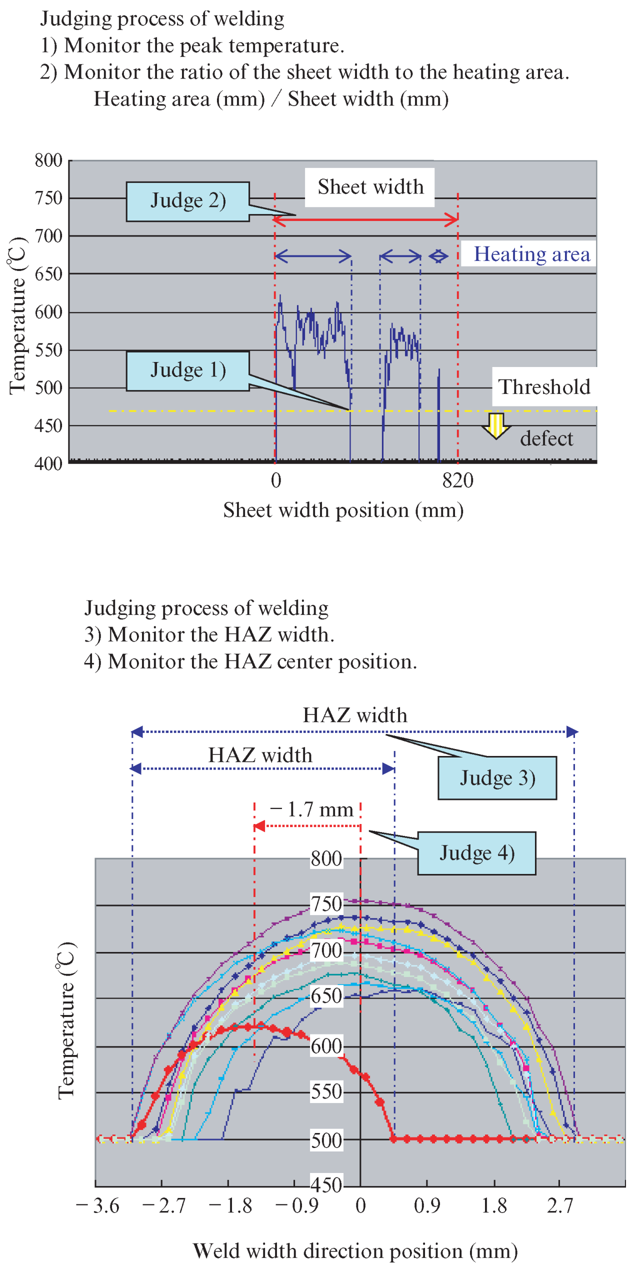

Fig. 12 Welding quality judgment logic

Defects can be detected to the positions of fine abnormalities in the HAZ by processing the above-mentioned judgment items in parallel. In addition, the measurement rests and judgment results are retained for a long period, and are also applied to trend value management of welding machines.

6. Conclusion

An effective 2D thermometer and judgment system for welding quality judgments was developed and introduced at the continuous annealing line (CAL) for tin plate at JFE Steel's East Japan Works (Chiba District) in 2013. Although that line was subsequently shut down due to consolidation of tin plate production at

JFE's West Japan Works (Fukuyama District), this technology was also deployed at the tin plate CAL at Fukuyama[3], where it is contributing to stable operation by introduction of judgment technology with further improved performance.

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