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An On-Line Detection System for Nonmetallic Inclusions in Tin Mill Black Plate for Drawing-Redrawing-Can-Making†

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Abstract:

JFE Steel has introduced an ultrasonic on-line detection system for nonmetallic inclusions in as-hot-rolled coil to be processed as tin mill black plate (TMBP). TMBP is used for draw and redraw (DRD)-can making, and requires high internal quality. It has been installed at No. 6 pickling line in East Japan Works (Chiba District). The detection result is rapidly fed back to the steelmaking process to improve steel cleanliness. As a result, TMBP coils have been kept in high internal cleanliness and defects found at users' DRD-can making processes have dramatically decreased.

1. Introduction

Drawing-Redrawing (DRD) can, a kind of 2-piece can, has advantages of good seal function and toughness against difference between internal pressure and external pressure. By making use of these advantages, DRD cans are applied to usages in which seaming and retort sterilization is made after food packing. For example, they are used as tuna cans and pet food cans[1]. In making of DRD cans, tin-free steel sheets excellent in paint adhesion[2] is painted beforehand and cans are made continuously by utilizing lubricativeness of the painted film. Usually, high-strength extra-thin steel sheets, namely tin mill black plates (TMBP) are used for DRD cans. The above steel sheets are manufactured from low-carbon Al-killed steel slabs through the processes of hot rolling, pickling, the first cold rolling, annealing, and the second cold rolling. The second cold rolling is made with a thickness reduction of tens of percents.

Because steel sheets for DRD cans, which have small thickness of 0.16 to 0.18 mm, are subjected to drawing multiple times, they are required to have high internal cleanliness. **Photo 1** shows an example of a body crack formed in manufacturing of DRD can. The crack is originated from a nonmetallic inclusion. If a crack pierces through a can body, serious trouble will happen after

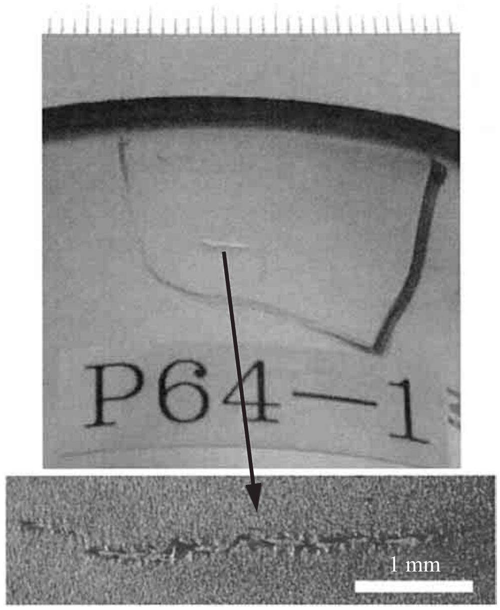

Photo 1 An appearance of surface breaking crack in DRD-can making

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Conventionally, to evaluate nonmetallic inclusions (otherwise flaws) in TMBP, magnetic particle testing (MT)[3] and magnetic flux leakage (MFL) testing[4] have been used. However, since only sheet samples can be evaluated by use of the conventional MT, customers have demanded flaw detection throughout the entire volume of a coil. As for on-line flaw detection in the cold rolling process using the conventional detector based on MFL technique, time lag from the steelmaking process to the detection of nonmetallic inclusions in the cold rolling process is so long that lengthy time is required until the detection results are fed back to the steelmaking process.

In view of this situation, JFE Steel has developed an on-line high-frequency ultrasonic detecting system for internal non-metallics in as-hot-rolled steel strip (OHDIN)[5,6] and has installed it in the No. 6 pickling line in the No. 1 cold rolling facilities at East Japan Works (Chiba)[7]. This report outlines OHDIN as installed in the No.6 pickling line, its operation method, and its usefulness.

2. Development of OHDIN in No. 6 Pickling Line

2.1 Flaw Detection Method and Its Features

Figure 1 shows an outline of a flaw detection method developed and used in OHDIN. A transmitting probe array and a receiving probe array are arranged opposite each other in water, with a steel strip interposed. A line-focused ultrasonic beam (25 MHz in frequency) is sent into the steel strip and two flaw echoes given as follows are received by the receiving probe array. Hereinafter, this method is referred as a flaw detection method using ultrasonic line sensor.

(1) Flaw echo reflected first at a internal flaw and next at the surface wall of the strip.
(2) Flaw echo reflected first at the back wall of the strip and next at a internal flaw.

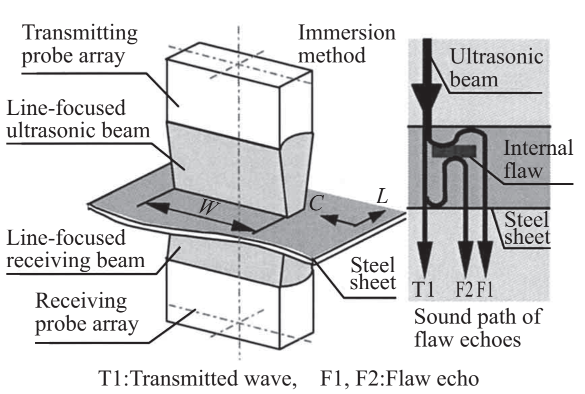

Fig. 1 Schematic geometry of ultrasonic probes

A certain linear area in the strip can be tested within a cycle of ultrasonic pulse repetition by combining simultaneous transmission of the line-focused ultrasonic beam by each element of the transmitting probe array with parallel processing of signals received by the receiving probe array. This flaw detection method is applicable to the continuous detection of internal flaws in the running steel strip.

The above-described flaw detection method has, without regard to use of the line-focused beam, detectability, which is equal to that of a conventional flaw detection method using a spot-focused beam. It is said that owing to low focusing gain, the detectability of the conventional flaw detection method using the line-focused beam is considerably lower than that of the conventional flaw detection method using the spot-focused beam. Therefore, in the developed method, sound pressure of flaw echoes is enhanced by the following two contrivances[8]:

(1) The focusing gain is increased by enlargement of the aperture of the transmitting and receiving probe. The aperture was enlarged without a decline of the sound pressure of outgoing wave from the probe by carefully selecting the piezoelectric material for the probe.
(2) The focal points of transmitting beam and receiving beam and the flaw are positioned as follows so that the flaw echo, which spreads as a spherical wave, is received before the wave diverges considerably.
   (a) The transmitting beam is focused on the flaw.
   (b) The flaw is positioned between the focal point of receiving beam and the receiving probe.

Many samples were tested by this method in the laboratory. **Figure 2** shows the size of nonmetallic inclusions detected by this method with a signal-to-noise ratio above 10 dB. Representative cross-sectional

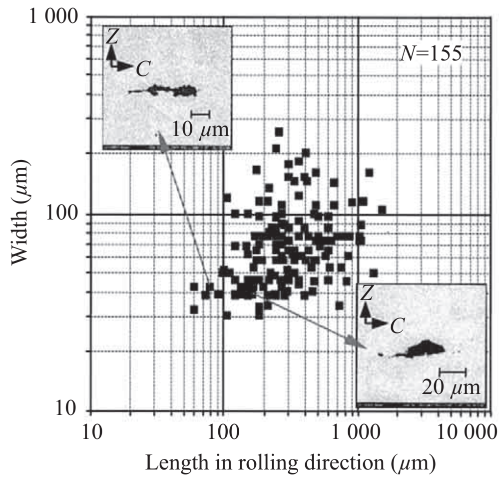

Fig. 2 Relation between width and length of flaws detected with signal-to-noise ratio above 10 dB

views of detected nonmetallic inclusions are also shown in Fig. 2. As a result of employing these contrivances, it has been proved that the nonmetallic inclusion with 5×10^{-5} mm^3 in volume can be detected with signal-to-noise ratio above 10 dB.

Another feature of this flaw detection method is that no dead zone right under the surface exists theoretically[8].

2.2 Development of a Non-metallic Inclusion Detecting System for Practical Use and Its Installation in Production Line

After the research and development of a water immersion mechanism for detecting flaws in a steel strip transfer line without disturbances of air bubbles[9], an ultrasonic detecting system (OHDIN, otherwise the detecting system) using the method mentioned above has been developed and installed in the No. 6 pickling line in No. 1 cold rolling facilities at East Japan Works (Chiba). **Figure 3** shows a schematic geometry of detecting heads (a transmitting probe array and a paired receiving probe array are designated as a detecting head in the following description.) and a block diagram of the ultrasonic detecting system. Steel strip being tested is immersed in water by using 6 additional deflector rolls. It is possible to carry out continuous flaw detection of the whole width of the steel strip by arranging detecting heads in an alternate manner as shown in Fig. 3. Accurately matching the impedance of the transmitting probe with the impedance of the pulsing circuit and also matching the impedance of the receiving probe with the impedance of the receiving amplifier eliminate influence of connecting cables on ultrasonic signals. A C-shaped frame retractable out of the production line was used to make maintenance work easy. A marking device, which enables putting a mark on the strip to indicate the position of detected flaw, is equipped for the purpose of getting samples of the detected flaws.

The detecting system carries out flaw detection according to testing conditions set on the basis of coil information sent from a host computer. During flaw detection the detecting system handles the detection data and organizes the detection results. After the completion of flaw detection throughout a coil, the detecting system returns the detection results to the host computer.

2.3 Verification of Detectablity in On-Line Detection

After the verification of good reproducibility of flaw detection results obtained by use of the detecting system, detectability of the detecting system in on-line flaw detection was verified by the following procedure:

(1) If a flaw is detected, the position where the flaw is detected is marked by the marking device. The marked portion is cut out from the strip as a sample.
(2) The position of flaw in the sample is determined exactly by using the ultrasonic line sensor in the laboratory.
(3) The length, L and width, W of the flaw are measured by use of C-scan presentation obtained by ultrasonic C-scan testing (frequency: 50 to 200 MHz).
(4) The position in the flaw to be observed sectionally is determined from the flaw image in the C-scan presentation and the flaw is sectioned.
(5) The thickness t_f of the flaw is measured by cross-sectional observation using a microscope. Then the volume V of the flaw is calculated by the equation: $V = L \times W \times t_f$.

Figure 4 shows the relation between the echo heights recorded in on-line detection and the volume of nonmetallic inclusion sampled through the above-described

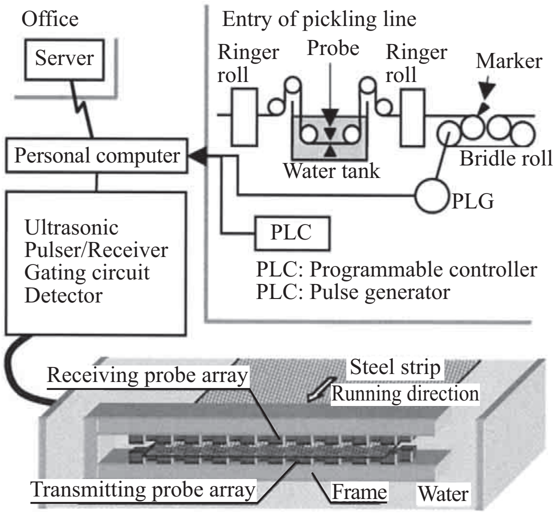

Fig. 3 Schematic geometry of detecting head and block diagram of detecting system

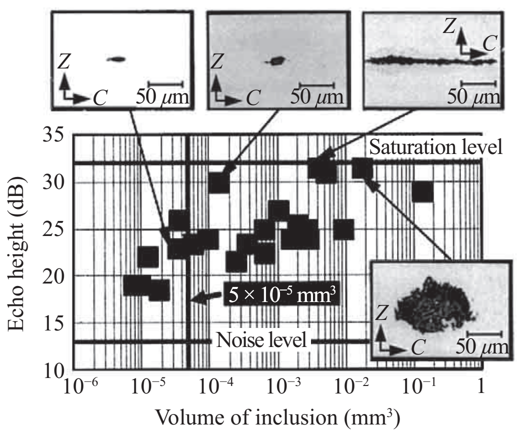

Fig. 4 Relation between echo height and volume of detected non-metallic inclusions

procedure. Representative cross-sectional views of detected nonmetallic inclusions are also shown in Fig. 4. It is confirmed that an inclusion with 5×10^{-5} mm^3 in the minimum volume can be detected with signal-to-noise ratio of approximately 10 dB. The detectability in on-line testing was equivalent to that in the experiment in the laboratory. As for the conventional MFL testing, it is said that the inclusion with a volume 5×10^{-4} mm^3 is critical for the detection[4,10]. The inclusion, which is 1/10 times smaller in volume than the conventional critical one, can be detected by use of OHDIN. There were no false indications in above-mentioned tests. Some false indications against which countermeasures had been taken and a small number of surface flaws detected were not classified as false indications.

3. Operation of OHDIN in No. 6 Pickling Line

3.1 Nonmetallic Inclusion Information System

A nonmetallic inclusion information system has been built in order to rapidly feed nonmetallic inclusion information obtained by OHDIN in the No. 6 pickling line back to the steelmaking process. The system configuration is shown in **Fig. 5**. The nonmetallic inclusion information and coil information are sent to the host computer so that a database in which the nonmetallic inclusion information is related with the operating conditions in the steelmaking process is built. The system shows information required for quality control on the basis of the database. Examples of factors to be operated in the steelmaking process are shown in **Table 1**. A change in a nonmetallic inclusion index is shown in **Fig. 6** as an example of nonmetallic inclusion information. In Fig. 6, the nonmetallic inclusion indexes for each coil are sorted in the order of slab cutting. The system has a function which enables quick comparison between the nonmetallic inclusion index and 162 items of operating conditions of converter refining, secondary refining, and continuous casting. The nonmetallic inclusion information is disclosed to all persons in charge of quality control in each section and can be accessed from network computers.

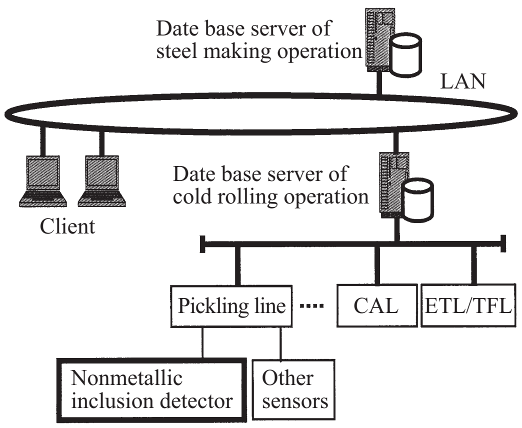

Fig. 5 Nonmetallic inclusion information system

Table 1 Factor of steel making process

Process	Operation data
Refining	Tapping component, Tapping temperature, Slag component, Basic unit, etc.
Secondary refining	Treatment time, Treatment gas volume, Degree of vacuum, Slag component, Basic unit, etc.
Continuous casting	Casting speed, Temperature, Abnormality of slab, Basic unit, etc.

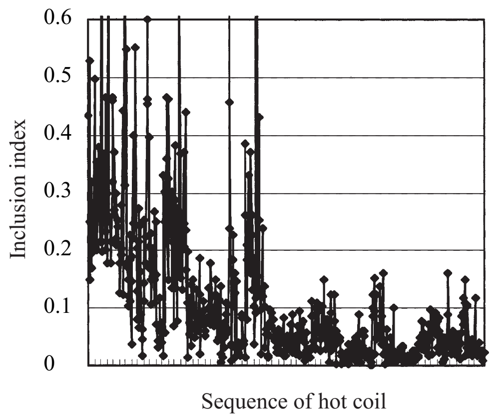

Fig. 6 An example of trend in inclusion index

By comparing the manufacturing conditions in the steelmaking process with the nonmetallic inclusion information, it has become possible to rapidly optimize the manufacturing conditions. The nonmetallic inclusion information from OHDIN in the No. 6 pickling line is effectively used also for a keeping of high quality and improvements of yields. As for the conventional nonmetallic inclusion detector using MFL technique installed in the cold rolling process, time lag from the steelmaking process to the detection of nonmetallic inclusions in the cold rolling process is so long that it was required lengthy time to carry out corrective actions in the steelmaking process. However, since time lag from the steelmaking process to pickling process is as short as several days, the period that is required to take corrective actions has been shortened by use of information obtained by using OHDIN in the No. 6 pickling line.

3.2 Maintenance and Calibration

Since OHDIN was developed by JFE Steel based on its original research, it was necessary to newly build methods to maintain and calibrate the detecting system. In order to use the detecting system for quality assurance of products, it is important that the detecting system have sufficient detectability and high reliability.

Therefore, the following operating methods have been built and standardized.
(1) A method for keeping detectability
(2) A method of daily check

3.2.1 Calibration method

The detecting heads are arranged on a C-shaped frame as shown in **Fig. 7** so that the detecting heads can be retracted out of the production line during the operation of the production line. This makes maintenance work easy.

The important point to keep the detectability of the detecting system is to keep the transmitting probe array and the receiving probe array, that are opposed to each other with the steel strip interposed, in the prescribed positional relationship. If the point is gained, constant high detectability can be kept. To evaluate the positional relationship mentioned above, the detecting system has a test piece and a probe positioning mechanism.

Figure 8 shows a simplified waveform of the ultrasonic signal obtained by the detecting system. The positional relationship between the transmitting probe array and the paired receiving probe array is adjusted so that the first through-transmitted wave T1 and the second through-transmitted wave T2 have amplitudes within each prescribed range. The positional relationship is adjusted not only on the occasion of the replacement of a probe array and the findings of a probe with insufficient sensitivity in the daily check described later, but also periodically at determined intervals.

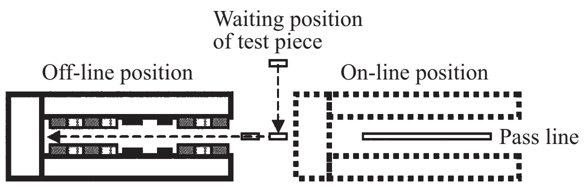

Fig. 7 Movement of test piece at sensitivity adjustment

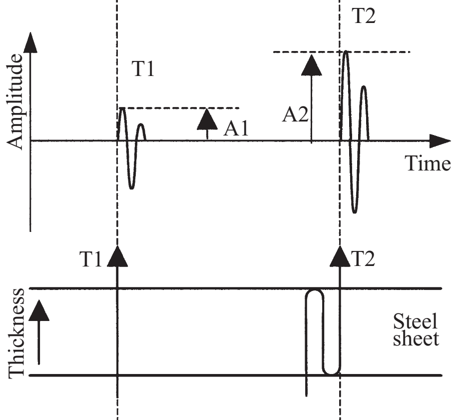

Fig. 8 A waveform of signals received by receiving probe array

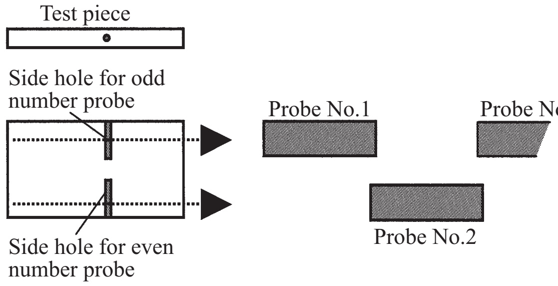

Fig. 9 Test piece and scanning method over probes

3.2.2 Daily check method

In utilization of OHDIN as a quality assurance instrument, if check results go out of the tolerable range, it is necessary to treat all products processed after the last check as vague quality products, which may have low internal quality. To avoid occurrence of massive vague quality products, it is necessary to prepare a check method, which can be carried out easily at short intervals.

Figure 9 shows the shape of a test piece used in daily check. As shown in the figure, a sensitivity reference hole of a prescribed diameter was made in the test piece. The amplitude of the hole-echo is measured at all channels in the offline position shown in Fig. 7 and is calibrated to predetermined amplitude. If a gain of the receiving amplifier exceeds a predetermined value, the sensitivity of the probe is judged to be low and the probe is replaced.

The diameter of the sensitivity reference hole made in the test piece is measured using an instrument with an assured traceability system. As a result, the measured sensitivity can be related to national and international standards to ensure high reliability.

3.2.3 Standardization and other check items

The above-described gain calibration and daily check methods are standardized. In order to maintain and check the detecting system, in addition to the above controls, there are many other items to be checked as described below:
(1) Water quality in the water tank (turbidity, temperature, number of air bubbles)
(2) Pass line level of the steel strip
(3) Deformation of test piece
(4) Working of the data processor

4. Quality Improvement

Figure 10 shows the defect index of DRD cans manufactured by customers who use JFE Steel's TMBP. The index of 2002 is normalized as 1.0. In 2003, OHDIN in the No. 6 pickling line began to be used as a qual-

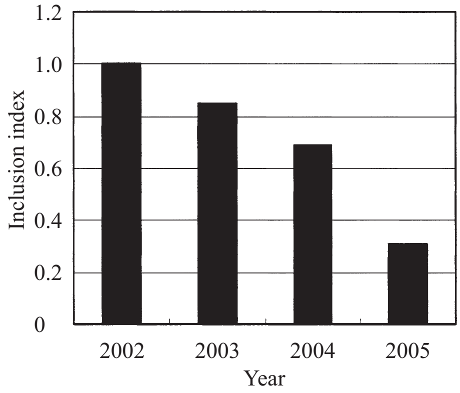

Fig. 10 Recent trend in inclusion index of product

ity assurance instrument and the nonmetallic inclusion information system was built. As a result, it has become possible to rapidly feed nonmetallic inclusion information back to the steelmaking department and the conditions of the steelmaking have been optimized. The defect index has been greatly improved.

5. Conclusions

For quality assurance and quality control of TMBP for DRD cans, an ultrasonic nonmetallic inclusion detecting system (OHDIN) was installed on the entry side of the No. 6 pickling line of the No. 1 cold rolling facilities at JFE Steel's East Works (Chiba). After the verification of detectability and the development of an operation method described below, the detector is in operation as a quality assurance instrument:

(1) It was confirmed that a nonmetallic inclusion with 5×10^{-5} mm^3 in the minimum volume can be detected with signal-to-noise ratio of approximately 10 dB in on-line condition.

(2) A sensitivity calibration method and a daily check method have been developed and standardized.

Furthermore, an information system, which enables nonmetallic inclusion information to be rapidly fed back to the steelmaking process and to be showed comprehensively, was built. As a result, the quality of TMBP for DRD cans was greatly improved and defects in DRD cans manufacturing were also greatly reduced.

At present, JFE Steel is considering the installation of this detecting system in other production lines so as to improve internal quality of other steel sheet products.

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