Recent Development of Nondestructive Inspection and Its Problems in Japanese Steel Industries*

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I. Introduction

Nondestructive inspections have become of a pressing need to ensure product quality in all industries as a matter of course and are employed in numerous practical applications. In modern industries that are pursuing high economy and reliability of products, not only quality assurance inspections are specified by users but effective in-process inspections are required by manufacturers to verify product quality being engineered. Nondestructive inspections meet this need. Actually and quite naturally, the inspections have made a rapid progress as the best means for quality assurance.

The Iron and Steel Institute of Japan (ISIJ) lately held the 46th and 47th Nishiyama Memorial Lecture on the theme "Recent Progress of Nondestructive Inspection Techniques," on the occasion of which the recent tendency of nondestructive inspections was enlarged upon. Individual inspection methods are described in the text¹⁾ used in the Lecture.

The author would like to report additional papers released thereafter and also to introduce the present status of automatization of nondestructive inspection in the steel industry, and problems to be solved in the future. This report has been prepared on the basis of questionnaire formerly made as to the nondestructive inspection techniques as one of the sectorial research activities of the ISIJ Joint Research Society.

In this report, however, the author wishes to deal chiefly on the following nondestructive inspections: ultrasonic, magnetic particle, radiographic, and eddy current flaw detection.

II. Present Status of Automatization of Nondestructive Inspection in Steel Production

1. Nondestructive Inspection of Semi-finished Products

Table 1 shows the number of steel works which now use automated nondestructive inspection equipment. These data are based on the questionnaire as to the theme "Present Status and Problems of Automatization of Nondestructive Inspection Equipment" discussed in November, 1977, at the 37th meetings of Quality Control Committee of the Joint Research Society, ISIJ.

According to this table, as of that time, most of steel works in Japan adopted automated ultrasonic equipment for inspection of plates, hot and cold strips, while only one works utilized automated equipment for flaw detection of slabs. However, every works is trying to introduce nondestructive flaw detection methods at slab stages. For example, the following methods have been studied: a method for detecting flaws at the surface of continuously cast slabs by the use of 0.5 to 1 MHz ultrasonic surface waves with local water-immersion coupling²⁾; a slab surface inspection method using beam scanning type wheel

Table 1. Present status of automatization of nondestructive inspection in iron and steel industry.*

Kind of product to be inspected	No. of works using automatic nondestructive inspection equipment (Method-wise number of works is given in parentheses.)
Slab	1 (UT...1)
Billet	8 (UT...1, MT...2, ET...1, UT+MT...3, MT+ET...1)
Bar	7 (UT...1, MT...4, ET...1, MT+ET...1)
Wire rod	6 (MT...1, ET...5)
Plate	10 (UT...10)
Hot-rolled strip	13 (UT...13)
Cold-rolled strip	11 (UT...11)
Seamless pipe and tube	5 (UT+MT...2, UT+ET...1, UT+MT+ET...2)
Electro-resistance welded pipe and tube	6 (UT...1, UT+ET...3, UT+MT+ET...2)
Continuous butt-welded pipe and tube	5 (ET...5)
Spiral welded pipe and tube	4 (UT+RT...4)
UOE pipe	6 (UT+MT+RT...5, MT...1)

* The above table is in accordance with data prepared on the basis of a questionnaire by Quality Control Committee of the Joint Research Society, ISIJ.

UT: Ultrasonic testing; MT: Magnetic-particle testing; ET: Eddy-current testing; RT: Radiographic testing

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transducers cooled by an automated forced water circulation system to allow inspections of slabs below 300°C³⁾; and a method using ITV system with an electromagnetic mechanical shutter for detection of defects in hot slabs.⁴⁾ For the detection of internal flaws in hot slabs, it is expected that electromagnetic ultrasonic probes will come to be utilized in the near future.⁵⁾

In the meantime, automatic inspection equipment, particularly automatic magnetic inspection equipment, have come to be adopted to a considerable extent in inspecting billets for shapes, wire rods, bars and tubes as indicated in Table 1. Generally, a conventional magnetic particle method, though still in wide use, is giving way to a magnetic leakage-flux flow detection method at a rapid tempo. SAM (Sumitomo Automatic Magnetic) flaw detection system,⁶⁾ being very effective, is coming into wide applications not only to final products as to be mentioned later but to billets.

The SAM flaw detecting system utilizes magnetic sensitive diodes to detect magnetic leakage flux from flaws. This system comes in two types: a fixed probe type⁷⁾ and a scanning probe type.⁸⁾ The former is applied to inspect round billet by moving and rotating the billet to be tested, while the latter is adopted when inspecting square billet by using the scanning probe which is made up of a pair of flat surface stands and a corner flaw detecting stand.

The flat surface flaw detecting stand as shown in Fig. 1(a) consists of a couple of exciting magnets and scanning probes respectively. The exciting magnets are arranged on two parallel sides of a square billet and independently the scanning probes are positioned on the other two sides of the billet. Another stand of similar construction is coaxially mounted with the probes and magnets arranged at 90 degrees apart from ones on the above-mentioned stand. These two stands form one SAM system for inspection for flat surface discontinuities.

Figure 1(b) shows a corner flaw detecting stand.

As for conventional magnetic particle inspection, a mechanized magnetic particle pattern reading unit has recently come into use besides large equipment with mechanized magnetizing and magnetic particle applying units. An ITV method is its example.⁹⁾

The eddy current technique is also suitable for inspection of cracks and discontinuities at and near the surface. For inspecting cold billets, the adoption of the eddy current testing using new probes with feedback amplifying circuits has been reported.¹⁰⁾

2. Nondestructive Inspection of Products

1. Plates

To inspect flaws in plates, automatic ultrasonic equipment of either a water-jet coupled transmission method or a water-film coupled reflection method using double crystal probes are in wide use. The former is applicable up to relatively high temperatures without dead zone in through-thickness direction of the plate. The latter, on the contrary, features high sensitivity detection of finer inclusions and defects than the former despite the presence of dead zone in the direction of plate thickness. The number of probes mounted on an installation has been increased. The most up-to-date installation now in practical applications has 280 channel probes in 56 blocks (5 double crystal probes in each block) with a capacity of 100% coverage throughout the surface by single pass of the plate under test. This equipment has two outstanding features: one is extremely high-speed detection realized by floating the many blocks of probes on a water film,¹¹⁾ and the other is the adoption of an automatic sensitivity calibration and function inspection system which has eliminated the calibration and maintenance time.¹²⁾

Figure 2(a) shows a floating mechanism, while Fig. 2(b) for its follow-up characteristics. In the processing of flaw detection data, a realtime color graphic display and a line-printed pattern are practiced for the purpose of displaying classification and evaluation of the flaw detected.¹³⁾ Furthermore, a fully automatic data processing and evaluation system is in practical use which is capable of flaw evaluation in accordance with JIS G 0801 for manual examination.¹⁴⁾ Photograph 1 gives an example of inspection result on the color graphic display with the simultaneous test mode. Figure 3 is an example of the block diagram of the data processing system. The remarkable progress in the nondestructive inspection techniques—high-speed detection, automatic sensitivity calibration, automatic function checking, and auto-

Fig. 1. SAM inspection machine for square billet.

matic data processing and evaluation of flaws—adequately deserves praise. However, the computerized installation which, with the 280 channel probes, is capable of testing the entire volume of a plate only by a single travel of the plate, still has some problems. It is several times as large in size as a conventional equipment which tests with intervals of about 100 mm, and needs large installation and maintenance costs. From this, the way to design and build automatic thick-plate flaw detecting equipment in the future all on a similar, large scale and concept as the above one has being discussed with opposing both evaluations pro and con.

2. Hot- and Cold-rolled Strips

While the automatic ultrasonic plate flaw detection

Photo. 1. Graphic display of ultrasonic testing result of plate.

(a) Floating mechanism

(b) Characteristic of floating mechanism on plate oscillation

Fig. 2. Floating mechanism for ultrasonic plate tester.

Fig. 3. Ultrasonic testing system for steel plates.

system shows marked increase in number to approximately 20 sets now in operation in this country, ones for thin and medium thick (6 mm or less) sheets and strips by the Lamb wave method have made much more remarkable progresses in only 10-odd years after researches were started on the method. It is reported that, at the moment, the number of equipment in operation exceeds 50 sets.¹⁵⁾ Despite this rapid spread of the equipment, there still remain several problems to be solved, including the presence of dead zones in edges, hard discrimination of flaw signal from noise, a surface flaw from an internal flaw, and difficulty in evaluation of flaw signals indications.¹⁶⁾

3. Wire Rods

The most widely applied automatic wire rod flaw detection technique is eddy current testing in hot condition. Various ideas have been engineered into a flaw signal data processing system and a feedback system to the rolling mill pulpit. Some of the eddy current testing equipment have a capacity of sorting flaw signals of 900° to 1 200°C wire rods into seams, exfoliations, scratches and burns from flaw patterns and a warning system thereof.¹⁷⁾ The result of the questionnaire by the aforementioned 37th Quality Control Committee also indicates that there are various problems such as lack of accuracy, poor stability, and hard detection of long longitudinal linear flaws having nearly the constant depth.

4. Bars

For the detection of flaws in bar steel, the eddy current testing and the aforementioned SAM flaw detection system are applied.^{18,19)} Beside this, the use of a one-man controlled fully automatic flaw detection system is reported.²⁰⁾ This system is a combination of an automatic magnetic leakage flux testing equipment in which a bar to be tested is moved straightly while the probe coils are turned around the bar, and an automatic ultrasonic testing equipment utilizing immersion-water film type double crystal probes, plus such auxiliary equipment as a bend detector, a deburring machine, a demagnetizer, and an automatic binder. Figure 4 shows the flaw detecting head of the automatic magnetic leakage flux testing

equipment and the scanning pattern of the probes. The probes are in contact, through a hard metal shoe, with the surface of the bar that passes at the center of the head, and turn at a high speed and scan spirally on the bar surface.

5. Pipes

Table 2 gives current status of nondestructive inspection of each type of steel pipes on the basis of the questionnaire made by the Steel Pipes and Tubes Committee of the Joint Research Society, ISIJ.²¹⁾ This table tells remarkable automatization and the number of automatic nondestructive testing equipment in use for steel pipes. The most interesting, in this table, is that, of 19 automatic magnetic testing equipments for seamless pipes (SML), 8 sets are SAM systems and 4 sets are AMALOG-SONOSCOPE systems. SAM, as reported, has no doubt spread most remarkably: 27 sets were in use in Japan for testing bars, pipes and round billets about one and a half years before March, 1978, when this questionnaire was issued.²²⁾ Various types of SAM sets have been developed: Type *S* for detection of outer surface flaws, Type *I* for inner surface flaws, Type *R* with a rotary head for longitudinal flaws, and Type *C* with multiple detectors for flaws in the circumferential direction.

Type *R* and Type *C* are so designed as to detect internal and external flaws from the outside by a DC magnetization. The AMALOG-SONOSCOPE is of the same type as the combination of these Types *R* and *C*. This system consists of an AMALOG having rotary head type magnetic poles and sensors for detecting flaws in the axial direction of a pipe, and an annular coil type SONOSCOPE having separately arranged, sensors for detecting flaws in the circumferential direction.²³⁾

Figure 5 shows schematic drawings of the AMALOG (a) and the SONOSCOPE (b); the former can detect axial flaws in a pipe and the latter, circumferential flaws.

The automatization of ultrasonic testing equipment is also very actively promoted as seen from the table. A problem arising in flaw detection of pipes is which we should choose, a pipe rotating method or

Fig. 4. Automatic magnetic inspection machine for round bar.

Table 2. Status of nondestructive inspection of steel pipes.* (Method-wise number of

Kind of pipe and tube	No. of works (companies) questioned	Blank (including mother coil and plate) and pipe product						UT	
		UT		MT		ET			
		Manu.	Auto.	Manu.	Auto.	Manu.	Auto.	Manu.	Auto.
Seamless	9 works (6 companies)	2 ws. (2 cos.)	9 ws. (6 cos.) 15 sets	2 ws. (2 cos.)	7 ws. (5 cos.) 19 sets	1 w. (1 co.)	8 ws. (6 cos.) 15 sets	— —	— —
Electro- resistance-welded	10 works (6 companies)	5 ws. (4 cos.)	7 ws. (4 cos.) 20 sets	4 ws. (3 cos.)	1 w. (1 co.) 2 sets	0 w.	9 ws. (6 cos.) 24 sets	5 ws. (4 cos.)	5 ws. (4 cos.) 23 sets
Continuous butt-welded	6 works (4 companies)	0 w.	0 w.	0 w.	0 w.	0 w.	6 ws. (4 cos.) 11 sets	0 w.	0 w.
Spiral-seam welded (SAW)	8 works (7 companies)	5 ws. (4 cos.)	5 ws. (4 cos.) 10 sets	4 ws. (3 cos.)	0 w.	0 w.	0 w.	5 ws. (5 cos.)	6 ws. (5 cos.) 9 sets
Straight-seam welded (SAW) UOE	6 works (4 companies)	5 ws. (4 cos.)	5 ws. (4 cos.) 8 sets	3 ws. (3 cos.)	3 ws. (3 cos.) 5 sets	0 w.	0 w.	6 ws. (4 cos.)	6 ws. (4 cos.) 8 sets

* The above table is in accordance with data prepared on the basis of questionnaire by Steel Pipes and Tubes Committee of the

Fig. 5. AMALOG-SONOSCOPE.

a probe rotating method. When testing large-diameter pipe, the probe rotating type is advantageous. Efforts are now being exerted to minimize noise in this type of testing. A large-capacity equipment has recently been developed for testing over 20 inch-diameter pipes.

6. Other Kind of Nondestructive Method

In Sections II. 1 and 2. 1 through 5 above have been described the conventional ultrasonic, magnetic, and eddy current testings of surface and internal flaws. The recent progress in automatization and mechanization of other than these conventional testing techniques is also great as described below.

(1) Optical Detection of Surface Flaws

Because of the difficulty in measuring conditions for the detection of flaws in hot surface of rolled products, testing equipment for these flaws are still at the stage of experimental manufacture or field experiments. Testing equipment made on an experimental

basis are, for example, the ITV system with an electromagnetic mechanical shutter described in Section II. 1 and a flying-image scanning type infrared camera. In the meantime, testing equipment for the detection of flaws in cold stage steel products are in considerably wide practical applications. To test cold-rolled strips having clean surfaces, a visible light is emitted to the surface and flaws, if any, can be detected by intensity variations of the reflected light. In this method of testing, the light source and the field of view of a detector element are both fixed or either of them is scanned. Another optical detection equipment is a pinhole detector utilizing photo-multipliers to detect leakage rays passing-through pinholes in black plate for tinplating, silicon steel and other extremely thin steel strips.

(2) Hardness Measurement²⁴⁾

In the eddy current hardness method, there is a nearly linear relationship between hardness and initial magnetic

works holding NDI)

Welded part					
MT		ET		RT	
Manu.	Auto.	Manu.	Auto.	Manu.	Auto.
—	—	—	—	—	—
—	—	—	—	—	—
5 ws. (3 cos.)	2 ws. (2 cos.) 2 sets	0 w.	9 ws. (6 cos.) 31 sets	0 w.	0 w.
0 w.	0 w.	0 w.	3 ws. (3 cos.) 7 sets	0 w.	0 w.
2 ws. (2 cos.)	0 w.	0 w.	0 w.	8 ws. (7 cos.)	7 ws. (6 cos.)
3 ws. (3 cos.)	3 ws. (3 cos.) 4 sets	0 w.	0 w.	6 ws. (4 cos.)	5 ws. (4 cos.)

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permeability and also the initial magnetic permeability has a linear relation with the deflection of secondary coil voltage. That is, the eddy current method is capable of measuring hardness nearly linearly. By utilizing this characteristics, hardness of black plate for tinplating is measured in the continuous annealing line by the use of an uncontact type continuous hardness tester. Continuous hardness measurement by the use of physical properties having a high correlation with hardness has been experimented to the largest degree.

(3) On-line Chemical Analysis²⁵⁾

For on-line fluorescence X-ray analysis of the chemical composition of rolled steel, a high-sensitive discrimination system of steel grade has been realized by using Si(Li) semiconductor as detector elements.

III. Present Status of Automatized Nondestructive Inspection of Welds in Steel Structures

Steel products so far described are mass-produced products of simple shape and size; and therefore the automatization of nondestructive inspection techniques for flaws in these products is rather easy. However, when these products are built into structures, the inspection will meet much difficulty because of unique forms and fixed conditions of structures. In the testing of such structures, the automatization to detect flaws in weld ultrasonically is relatively advanced. It is primarily because of an increased volume of testing work for the verification of soundness of welds which has become of great importance, and secondarily because of necessity for enhancing the reliability of the ultrasonic testing which is inferior in recording ability and objectivity of indications to the radiographic testing.

The shipbuilding industry first started the automati-

zation of the ultrasonic inspection,²⁶⁾ developing a self-propelled flaw detecting car.²⁷⁾

In the civil engineering and construction industry, automatic flaw detectors are in use for testing flaws in welds in H-shape steel, thus eliminating inconvenience and hazard in manual testing at high places.^{28,29)}

Longitudinal seams and spiral welds of pipes are automatically inspected at steel works as described earlier. For testing flaws in circumferential joints of pipeline, self-propelled testing equipment are in experimental and/or practical use, overcoming a difficulty in discriminating penetration bead echoes from a flaw echoes.^{30,31)}

Pipe structures other than pipelines are chiefly found in marine applications. Especially in tubular joints of the marine pipe grid welded structures, flaw signal evaluation and classification will become very difficult, since the pipe wall thickness to outer diameter ratio (t/D) varies during scanning of probe near the pipe penetration joints and accordingly the beam propagation path and the probe distance change. To cope with this difficulty, researches are being actively carried on.³²⁻³⁴⁾ It is expected that automatic weld flaw detectors will be developed in near future.

In the field of nuclear power industry, "safety" is most important. Nuclear reactor pressure vessels and primary coolant pipelines are subjected to strict inspection not only during manufacture but also in service. These inspections are incomparably stricter than those in other general industries.

The inspection results must satisfy the requirements of "In Service Inspection (ISI)" for nuclear reactor coolant pressure boundary. A flaw detector driving unit is provided with various protective and safety devices and is capable of remotely controlled in order to prevent accidental exposure to radiation.³⁵⁾

In the case of pressure vessels for other than the nuclear power industry, it is considered that an emphasis will be placed not only on the development of intermediate and final inspections, but also on that of ISI for the entire body of the vessel as well as welds. From this point of view, they are making strenuous efforts in research of acoustic emission (AE) technique in an attempt to develop new means of on-line monitoring. At present, therefore, it may be said that an important task is to grasp AE characteristics of materials quantitatively.³⁶⁾

IV. Future Problems of Nondestructive Inspection

The nondestructive inspection techniques have no doubt made an astonishingly great progress, being mechanized and automatized in rapid succession. Most of these newly developed techniques, however, are for accurately locating defects. Very few researches have been made on the evaluation of harmfulness of defects. This is a matter for regret.

When nondestructive inspection are performed as intermediate inspection measures for quality control, flaw evaluation standards will have a direct effect on

the final yield of products and the value of the products after delivery, and, therefore, must be always checked and be corrected when needed. However, when the inspections are conducted as delivery or final inspections for quality assurance purpose, flaw evaluation standards are in most cases not always adequate.

Most surface flaws can be decided to be harmful or harmless during the subsequent fabricating process and are easily repairable if they are decided harmful. On the contrary, internal flaws are hard to evaluate and to repair.

In the case of a plate, for example, which is of the simplest shape and is very often tested for flaws, the ultrasonic testing is suitable for and capable of accurate detection of internal flaws. Nevertheless, as for the established standards for flaw evaluation at the time of delivery and receiving inspections, in Japan, only one standard exists; JIS G 0801 "Ultrasonic Examination of Steel Plates for Pressure Vessels". Acceptance limit of internal flaws in structural members varies with service conditions of the parts and therefore it is ideal to establish a criterion by each part. In this so-called mass-production age, a statistical standard is allowed to some extent. Actually, however, the only authorized standard mentioned above is intended primarily for steel plates for pressure vessels as so titled. Despite the title, the standard is used in practical inspection, regardless of types and intended purposes of steel, wherever the ultrasonic testing is specified. This is a wrong tendency.

The nondestructive testing of welds has more serious problems than those of base metal. In conventional inspection of welds, the ultrasonic method has rapidly come to be used in place of the radiographic testing. Researches have also been carried out thereof, reporting that a considerably large error will occur depending on the effect of various kinds of reflective waves which vary with the location and inclination of flaws.³⁷⁾ This problem, however, will shortly be solved by promoting automatization of testing and measurement and accuracy improvement.³⁸⁾ Criteria for measurement and testing, however, are still immature excepting ASME Boiler and Pressure Vessel Code, Mandatory Appendix G of Section III, Protection Against Nonductile Failure (1972). This criterion is established on the basis of fracture mechanics. Japanese standards for welds of steel structures, however, are not necessarily satisfactory to adhere to. It may be said that these standards are developed to establish the flaw evaluation standard equivalent to that of conventional radiographic testing.

In short, the present progress of the nondestructive inspections is too much dependent on the progress of flaw detecting techniques. The author wishes to insist that research activities such as those of "003 Special Committee (Special Research Committee for Defective Material Evaluation)" of the Japanese Society for Non-destructive Inspection should be promoted in a nation-wide scale by all industries and all research societies and organizations.

The "Journal of NDI" recently published contains a report that gives various problems as to the evaluation of flaws in connection with the strength of steel materials,³⁹⁾ which were formerly reported at the "003 Special Committee" meeting, stating its desire to design and material divisions and further introducing problems on safety and reliability of steel and a trend of research activities. In view of the rapid growth of nondestructive inspection techniques, it is expected that such research activities will become much more active.

V. Conclusion

This paper has reviewed a recent rapid progress in the field of nondestructive inspection techniques in Japan and the present status of automatization of the techniques in the steel industry and further referred to the future development of flaw detecting techniques and the necessity of rapid progress in the research of flaw evaluation.

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REFERENCES

- 1) Text used at the 46th and 47th Nishiyama Memorial Lecture, ISIJ, (1977).
- 2) K. Miyagawa, K. Amano, T. Okubo, M. Ōta, H. Matsuyama and K. Kōno: *Hihakai Kensa*, **26** (1977), 618.
- 3) T. Shiraiwa, H. Yamaguchi, S. Matsumoto, A. Nakanishi, A. Takahashi and H. Ban: *Hihakai Kensa*, **27** (1978), 140.
- 4) T. Hiroshima, K. Matsui and T. Maki: *Hihakai Kensa*, **27** (1978), 152.
- 5) K. Kawashima: *Tetsu-to-Hagané*, **63** (1977), S703.
- 6) T. Shiraiwa, T. Hiroshima and T. Hirota: *Sumitomo Metals*, **27** (1975), 365.
- 7) T. Shiraiwa, T. Hiroshima, T. Hirota, S. Mitsunari, Y. Fujii and A. Takahashi: *Sumitomo Metals*, **26** (1974), 39.
- 8) T. Hiroshima, T. Hirota, A. Moriya, K. Yamashima and M. Yamane: *Sumitomo Metals*, **30** (1978), 154.
- 9) M. Hinami, M. Ishiyama, S. Yoshimura, N. Matsubara, Y. Kido and Y. Tanaka: *Sumitomo Metals*, **28** (1976), 134.
- 10) K. Shimada, I. Komine, S. Kakuzaki, M. Yamada and H. Tanabe: *Tetsu-to-Hagané*, **64** (1978), S248.
- 11) H. Domon, Y. Matsuoka, H. Miyawaki and S. Marumoto: *Hihakai Kensa*, **27** (1978), 626.
- 12) H. Domon, Y. Matsuoka, S. Murashima, Y. Kojima and H. Matsuyama: *Hihakai Kensa*, **25** (1976), 750.
- 13) Y. Uno, H. Morita and K. Matsumura: *Hihakai Kensa*, **25** (1976), 750.
- 14) N. Matsumura, M. Koike, M. Nakakura and H. Matsuyama: *Hihakai Kensa*, **27** (1978), 630.
- 15) H. Matsumura: "NDI for Plates and Sheet," the 46th and 47th Nishiyama Memorial Lecture, ISIJ, (1977), 41.
- 16) Data for Subcommittee of NDI Conference, Quality Control Committee of the Joint Research Society, ISIJ, (1977).
- 17) N. Namiki, H. Hamamura, S. Watanabe and N. Matsubara: *Sumitomo Metals*, **25** (1973), 327.
- 18) T. Shiraiwa and T. Hiroshima: *Tetsu-to-Hagané*, **57** (1971),

- 139.
- 19) H. Hamamatsu, N. Matsubara, N. Ishimoto and T. Hirota: *Sumitomo Metals*, **25** (1973), 319.
 - 20) Y. Katagiri, Y. Uno, S. Katayama, H. Morita and K. Geko: *Tetsu-to-Hagané*, **63** (1977), S199.
 - 21) Data from Questionnaire by Steel Pipes and Tubes Committee of the Joint Research Society, ISIJ, (1978).
 - 22) T. Shiraiwa, T. Hiroshima, T. Hirota and T. Sakamoto: *Sumitomo Metals*, **28** (1976), 437.
 - 23) Keihin Works, Nippon Kokan K.K.: "AMT in Seamless Pipe Mill," the 64th Meeting of Instrumentation Committee of the Joint Research Society, ISIJ, (1976).
 - 24) K. Kawashima, S. Sekino, H. Domon, R. Toda, Y. Sasaki and S. Fujiwara: *Hihakai Kensa*, **21** (1972), 401.
 - 25) T. Shiraiwa and M. Fujino: *Tetsu-to-Hagané*, **64** (1978), A72.
 - 26) M. Kaneda, O. Mimura, K. Nakayashiki, H. Takizawa, M. Kishigami, H. Sekiguchi and H. Saitō: *Hihakai Kensa*, **22** (1973), 154.
 - 27) Y. Yoshitani, T. Ueno, N. Yokota, K. Miyagawa, E. Isono and S. Kamimura: *Seitetsu Kenkyu*, (1974), No. 280, 126.
 - 28) K. Ōta, E. Yamamoto, N. Fujimori and M. Kuramochi: *Hihakai Kensa*, **24** (1975), 641.
 - 29) T. Shiraiwa, H. Yamaguchi, S. Matsumoto, T. Tanaka and Y. Ogura: *Hihakai Kensa*, **25** (1976), 734.
 - 30) M. Nakayama, Y. Katō, K. Utagawa and E. Isono: *Hihakai Kensa*, **25** (1976), 720.
 - 31) T. Shiraiwa, H. Yamaguchi, S. Matsumoto, M. Tomabechi and K. Nakasima: *Hihakai Kensa*, **25** (1976), 728.
 - 32) Y. Kuhara, K. Obara, Y. Ishii and T. Ishida: *Hihakai Kensa*, **27** (1978), 606.
 - 33) Y. Kuhara, S. Arita, T. Inoue and T. Ishida: *Hihakai Kensa*, **27** (1978), 608.
 - 34) T. Shiraiwa, H. Yamaguchi, S. Matsumoto and T. Tanaka: *Hihakai Kensa*, **27** (1978), 610.
 - 35) Y. Sakurai, H. Yamada, J. Kaneko and K. Uchida: *Hihakai Kensa*, **25** (1976), 712.
 - 36) T. Kishi: "Measuring of AE and Evaluation of Materials," the 46th and 47th Nishiyama Memorial Lecture, ISIJ, (1977), 191.
 - 37) Y. Ogura: *Hihakai Kensa*, **27** (1978), 731.
 - 38) Special Edition for "Measurement of Height of Welding Defects," *Hihakai Kensa*, **26** (1977), No. 5.
 - 39) K. Uchino: *Hihakai Kensa*, **28** (1979), 30.