KAWASAKI STEEL TECHNICAL REPORT
No.16 (June 1987)

Ultrasonic Immersion Testing System

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1 Introduction

Ultrasonic flaw detection has emerged as a nondestructive examination method that requires none of the special protective measures needed with X-ray or γ-ray examination methods. Generally, this flaw detection only requires that an electroacoustic transducer, called a probe, be placed in contact with the object to be tested through an acoustic couplant such as water or oil. Results of flaw detection appear on the CRT screen of the flaw detector instantaneously by this operation. Therefore, one of the features of this method is that the operation can be conducted in a simple manner in any place. However, the reproducibility and accuracy of this method depended greatly on the skill of operators and objective records were not obtained; these were serious defects of this method.

Applications of nondestructive testing in the steel industry are broadly divided into the following categories, i.e., inspection for quality assurance, maintenance inspection of equipment, and testing for quality control. Among these, the most common application is quality assurance. In this application, areas specified in standards, specifications, etc. are subjected to flaw detection under predetermined conditions. If signals occur indicating a specified defect level, the object in question is rejected. Therefore, this flaw detection method is easily automated and automatic ultrasonic testing systems for steel plates and steel pipe have been developed.

It should be noted that these types of inspection are, so to speak, sampling inspection, and are not conducted to collect information on the entire volume of production. In tests for quality control, however, it is desirable that information on the entire volume be gathered. It has, perhaps, been considered impossible to apply ultrasonic flaw detection by manual scanning to the entire volume due to the instability of acoustic coupling and the inaccuracy of the scanning interval. However, this

* Originally published in *Kawasaki Steel Giho*, 18(1986)2, pp. 199-207

has become possible by an immersion type ultrasonic scanning flaw detection system, the C-scan system, developed to conduct precision scanning flaw detection of the entire area of a specimen.

This flaw detection method was first adopted by Kawasaki Steel in 1974 when a C-scan system manufactured by a U.S. company was introduced in the Research Laboratories for the purpose of evaluating inclusions in semi-finished products. The initial aim, i.e., replacement of the step-down particle test of CC (continuously cast) slabs, could not be accomplished due to the noise caused by the internal cast structure. However, ingot-cast steels were giving way to CC steels as material plates for UOE pipe at that time, and this flaw detection method proved very effective in measuring the levels of the non-metallie inclusions at the middle of the wall thickness which are peculiar to CC steels. Furthermore, this method is also useful for detecting the inclusions in hot strip edges which cause hook cracks, one of the typical defects in ERW pipe. Thus the C-scan method contributed to the reduction of inclusions in CC steels.

In the development of hydrogen-induced cracking resistant steel plate, this flaw detection method was established as a rapid nondestructive, quantitative evaluation method, replacing microscopic examination. Therefore, the C-scan method began to be introduced at the Mizushima and Chiba Works as an effective tool not only in reserch but also in on-site inspection.

Since the conventional C-scan system had certain problems, the joint development of a new system for introduction at the Mizushima Works was carried out by Kawasaki Steel Corp. and Kawatetsu Instruments Co., Ltd. in 1977.[1)]

Goals of this project were:

(1) Improved maintainability
(2) Flexible adaptability to upgrading of facilities
(3) Improved cost performance

The authors made efforts, from the technical viewpoint, to adopt a broadband probe just coming into use at that time and to use the type MARK-III ultrasonic flaw detector produced by the American firm, Sonic Instruments Inc. This probe was matched to the MARK-III flaw detector, which also came on the market at the time and was said to provide the best performance among ultrasonic flaw detectors. The combination of the Sonic Instruments MARK-III, a broadband probe, a precision scanning mechanism, and an immersion tank is still being used at present, with excellent results.

This paper describes the scanning control mechanism and data processing unit of this immersion type ultrasonic scanning flaw detection system, along with examples of its application and recent topics.

2 Outline of System

2.1 Principle of System

The C-scan system has the following features:

(1) High frequencies can be used because of the small acoustic absorption loss in water.
(2) Focusing by an acoustic lens is possible.
(3) Acoustic coupling is stable.
(4) The scanning accuracy is high.
(5) Clear, accurate records can be obtained.

The C-scan system is composed of an immersion type probe focused over a broad band, a scanning mechanism, a broadband flaw detector, a water tank which provides a sufficient water path and in which the object to be tested is immersed, a high-speed, high-accuracy recorder, and a control unit for these components.

The principle of the C-scan method is shown in **Fig. 1**. In this method, the probe is kept at a constant distance from the surface of the object to be inspected, and scans the whole surface to detect defects. At the same time, defects are recorded by a recording system synchronized with the probe, providing diagrams of the two-dimensional distribution of defects. A general view of the C-scan system is shown in **Photo 1**. The general composition and a block diagram of the system are shown in **Figs. 2** and **3**, respectively.

Based on scanning conditions set interactively using the CRT display and keyboard, scanning control signals are sent to a scanning drive unit as a basis for automatic operations. Manual operations, such as temporary stop and start of scanning, are performed using switches on the front panel of the carriage on the immersion tank.

Flaw signals, obtained by the probe and the flaw detector working in synchronization with the scanning mechanism, are transmitted to the recorder. At the

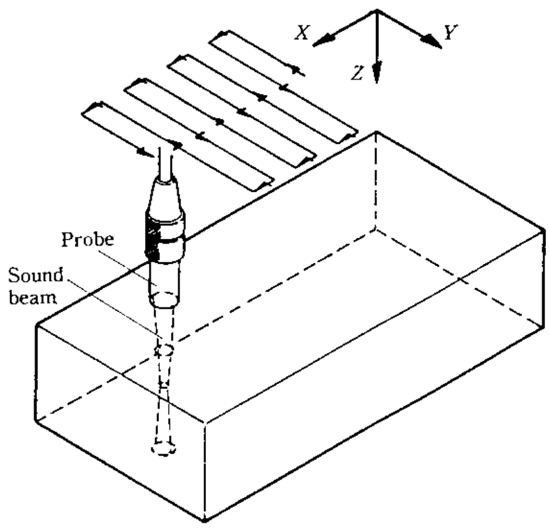


Fig. 1 Schematic representation of C-scan method

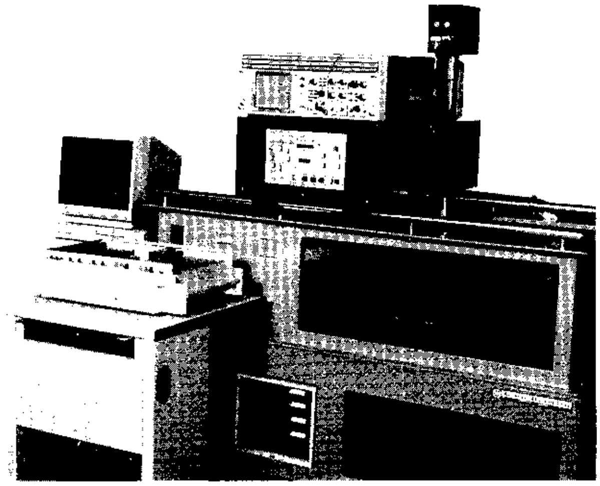


Photo 1 General view of C-scan system

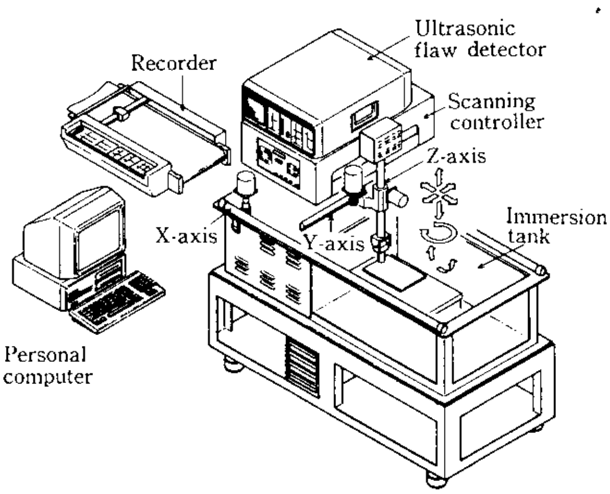


Fig. 2 General composition of the system

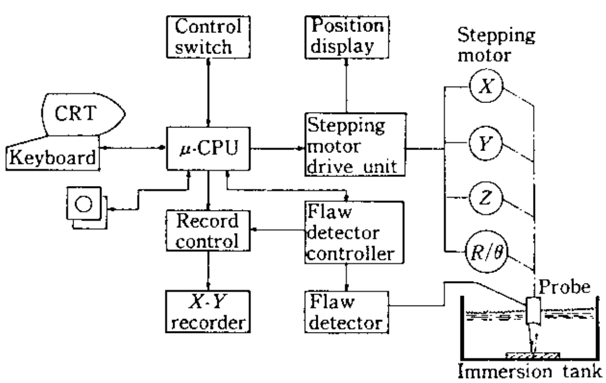


Fig. 3 Block diagram of C-scan system

same time, these are used for the statistical processing of the flaw ratio, etc.; this data is stored on a floppy disk for data retension and is used in producing the image display on the CRT screen.

2.2 Features and Specifications of System

More than twenty immersion type flaw detection systems were fabricated in the **KUSS** series until 1984, following the fabrication of the first system for the Inspection Section of the Mizushima Works in 1977.[1] In these systems, improvements were gradually made in response to user needs. These improvements were made mainly in the control system, and drive, manipulator, and data processing areas. In the first unit, control system was entirely of the wired logic type and was limited to only *X*-*Y* scanning. In the second and following units, microcomputer control was adopted; a one-board computer was used in the early stage, while in the recent type a 16-bit personal computer performs both control and data processing.

Scanning axes are the *X*- and *Y*-axes for plane scanning plus the vertical *Z*-axis; turntable rotation is also possible as an option. The manipulator has advanced from the manual goniometer type to a type in which the tilting angle and azimuthal angle are adjusted by a stepping motor. This type was developed to automatically scan axially symmetrical, cylindrical bodies in "NC" type movements. In this type, a personal computer computes amounts of movement of each axis by mathematical models to permit the flaw detection with objects having curvature.

Data processing in the first system was limited to the C-scope recording of *X*- and *Y*-axes, i.e., two-dimensional map recording of flaws. In the second and following systems in which microcomputer control was adopted, a unique three-dimensional image display function using computer graphic processing was realized in addition to the recording of B-scope graphics, calculation of flaw ratio, etc.

The specifications of the present C-scan system are listed in **Table 1**. The features of each component of the system are described in the following.

2.2.1 Ultrasonic flaw detector (MARK-III)

The flaw detector Model MARK-III, manufactured by Sonic Instruments Inc., can detect specimen defects, such as cracks and inclusions, as small as about 10 μm, by use of a combination of broadband and high-resolution pulser and receiver, a flaw amplifier, and a broadband focus type probe.

2.2.2 Scanning controller

Two types are in use, the three-axis type with *X*-, *Y*- and *Z*-axes, the basic scanning axes, and the five-axis type, in which the manipulator is motor-operated. Furthermore, a turntable, rotating chuck, and turning roller, mechanisms for rotating cylindrical bodies, round bars, etc., are provided as optional axes, making use of

Table 1 General specifications of KUSS series C-scan system

Designation			KUSS-10 series	KUSS-20 series
Scanning controller	Scanning axes		3 axes type	5 axes type
Scanning controller	Controlled axes		X, Y, and Z	X, Y, Z, R and θ
Scanning controller	Manipulator		Manual ±30°	Motor operated. $R=0°$ to 370° $\theta=-15°$ to 70°
Scanning controller	X-scanner	Scanning stroke	10 to 700 mm	
		Index pitch	0.1 to 9.9 mm	
		Position reproducibility	0.1 mm	
Scanning controller	Y-scanner	Scanning stroke	±50 to ±175 mm	
		Scanning speed	300 mm/s (max.)	
		Position reproducibility	0.1 mm	
Scanning controller	Z-scanner	Scanning stroke	10 to 800 mm	
		Index pitch	0.1 to 9.9 mm	
		Position reproducibility	0.1 mm	
Optional mechanism	Turn table	Material O.D.	60 to 800 mmϕ	
		Load bearing capacity	50 kg	
Optional mechanism	Rotating chuck	Material O.D.	20 to 400 mmϕ	
		Load bearing capacity	50 kg	
Optional mechanism	Turning roller	Material O.D.	60 to 400 mmϕ	
		Load bearing capacity	100 kg	
Immersion tank (Effective scanning area)			A: $600^L \times 300^W \times 300^D$ mm B: $700^L \times 350^W \times 300^D$ mm C: $800^L \times 600^W \times 600^D$ mm D: $3\,000^L \times 2\,000^W \times 800^D$ mm	
Data processor			· C-scope recording · Digital display of water path between probe and material surface · Computation and display of flaw area ratio	
Data processor	Options		· Gray scale recording · B-scope recording · Flaw data storage in floppy disk · Three-dimensional flaw display	
Recorder	Chart size		A3 (roll)	
	Scale		5/1, 2/1, 1/1, 1/2, 1/5 (desired enlargement and reduction also possible)	
	Recording		Electrosensitive system	
Flaw detector (Model MARK-III)	Frequency range		1 to 25 MHz	
	ATT. coverage		47 dB	
	Gain		80 dB	
	Pulse repeat frequency		250, 500, 1 k, 2k, 5 kHz, external	
	CRT size		120 × 100 mm	

the device possible with objects of any form. The scanning mechanism, which uses a stepping motor as the drive source and a rack and pinion mechanism as its main structure, features (1) high positional accuracy of up to 0.1 mm even in a large immersion tank, and (2) high-speed scanning of 300 mm/s maximum (Y-axis). Scanning control is conducted by computer processing using a 16-bit personal computer. In addition to simple scanning by two axis drive, it is possible to perform scanning with combinations of three to six axes, for example, scanning of a conical body using a combination of X-, Y- and Z-axes and the turntable axis.

2.2.3 Data processor

(1) Digital Display of Water Path
The water path from the front of the probe to the surface of the specimen is important as information in this type of flaw detection system which uses a focus type probe. Operatability is increased by the digital display of this information on the operation panel.

(2) B-scope Recording
In the A-scope obtained in real time, it is possible to obtain not only the echo height from flaws but position information on the depth of flaws as time base information. To obtain this position information, the specimen is repeatedly scanned along a straight line and a narrowed flaw gate is shifted along the time-axis for each scan. In this manner, B-scope patterns, i.e., patterns in the direction of the section can be obtained. B-scopes thus obtained are shown in **Fig. 4**. B-scopes have so far been obtained by computer processing or on a memory type CRT screen according to a hard structure; no examples are known of recordings taken in a similar manner to the B-scope recordings produced by this system. The position of flaws can be recorded with a resolution of 0.2 mm in the thickness direction of the specimen and flaws can be accurately located.

(3) Gray Scale Recording
This function is for obtaining depth information which is not necessarily so detailed as B-scope information, for example, for distinguishing between the surface layer and the central interior zone of a plate as is done in flaw detection with CC steels. In this case, two flaw gates are combined, logical operations are carried out, and results are recorded on C-scope recording paper as dark or light marks. An example of this type of recording is shown in **Fig. 5**. This is the result of flaw detection of a specimen which was taken from the top of a rolled slab and in which hydrogen-induced cracking had been caused. In this figure, the darkest areas indicate cracks present in the center of the plate thickness, while the less dark areas indicates cracks formed in other portions.

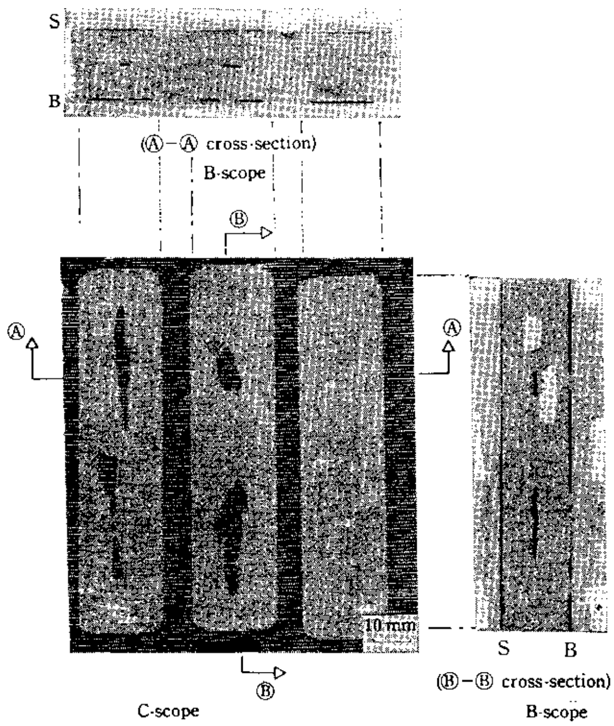


Fig. 4 Example of C-scope and B-scope of HIC specimens

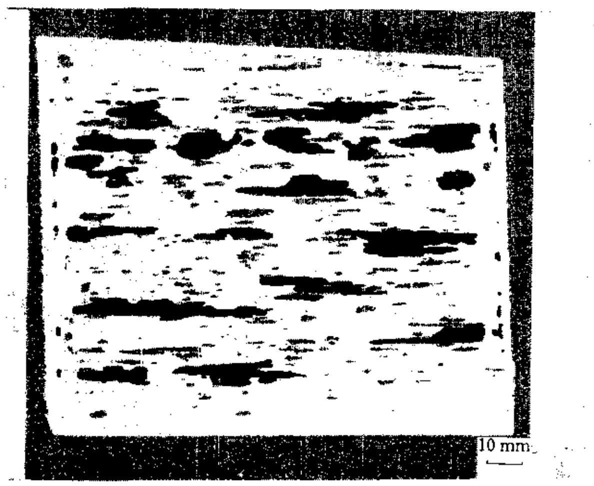


Fig. 5 Example of gray scale recording

(4) Display and Recording of Flaw Ratio
The calculation, display, and recording of the flaw ratio of two-dimensionally projected flaws in an effective area permit quantitative evaluation of flaws, in addition to their visual evaluation. Examples of flaw ratios printed on flaw recording paper are shown in **Fig. 6**.

(5) Permanent Recording of Flaw Data on Floppy Disk
Position coordinates of flaws detected during flaw

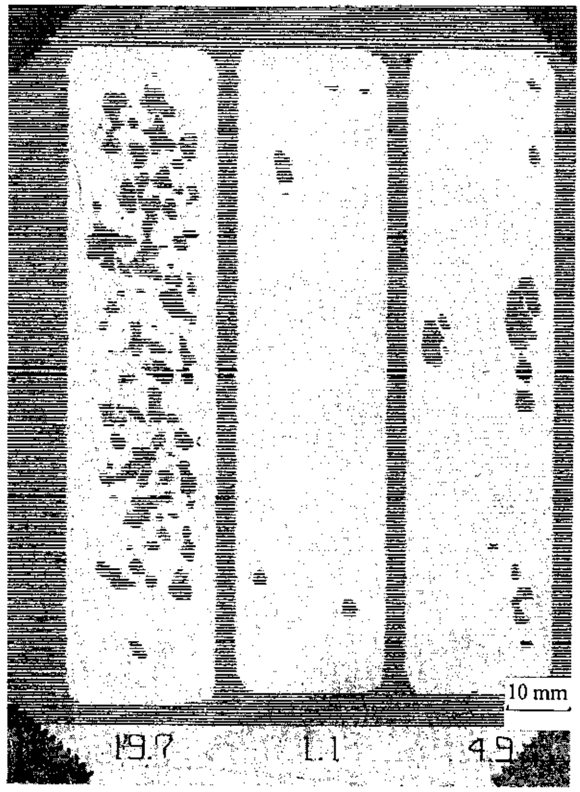


Fig. 6 Example records of flaw patterns with flaw ratio value printed

scanning, echo height of flaws, and on/off condition of alarms are recorded on floppy disks as data.

(6) Isometric Display
The function of the isometric display of flaws is available with the KUSS series of ultrasonic flaw detection systems as an option. This function has the following features:

(a) This optional function collects data in synchronization with the scanning mechanism and flaw detector during ordinary automatic scanning flaw detection and can record information of 8×10^6 item maximum; 200 item maximum for each of the three axes X, Y and Z (Z-axis indicating the thickness of the specimen).
(b) Collection data can be recorded on floppy disks, read out at any time, and displayed.
(c) Three-dimensional display from any angle can be obtained from keyboard instruction, allowing analysis of flaws from various angles.
(d) Furthermore, a projected graphic of internal defects can be displayed by this type of three-dimensional graphic.
(e) The echo height of flaws can be classified into seven levels and color displayed.
(f) The B-scope display and flaw ratio of the section of any of X-, Y- and Z-axes can be obtained.

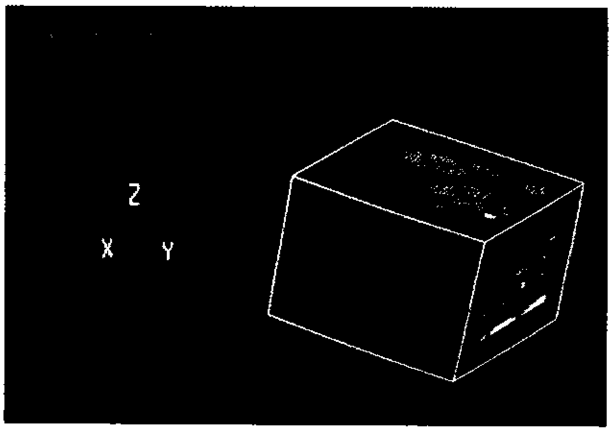


Photo 2 Example of isometric display with two-dimensional top and side views for ready identification of the three-dimensional distribution of flaw

An example of flaw detection, recording, and display by this function is shown in **Photo 2**. In this example, three-dimensional images of internal flaws are observed at the center; their top projection view is indicated on the top side and their side projection view on the right side of the rectangular parallelepiped. The specimen used is a overlay stainless clad steel, with cracks induced in the weld. Cracks in the weld can be distinguished from those in the carbon steel material. Therefore, this isometric display is used for investigating the propagation of cracks into the steel as well as for observing and evaluating cracks.

3 Typical Examples of Application of System

3.1 Application to Hydrogen-Induced Cracking Test[2)]

Important problems with line pipe steels are the hydrogen-induced cracking (HIC) in the base metal in an environment containing hydrogen sulfide and the sulfide stress corrosion cracking (SSC) in circumferential welds. In HIC, Fe and H_2S react on the internal surface of steel pipe to form hydrogen atoms which penetrate the steel and induce cracking. This immersion type ultrasonic scanning flaw detection system has been applied very effectively to the evaluation of the susceptibility of steels to HIC, i.e., through use in the HIC test.

What is called the BP test has so far been widely adopted as one of the HIC test methods. In this test method, multiple specimens at right angles to the rolling direction are cut from a test material placed for 96 hours under the standard test conditions shown in **Table 2**; these specimens are observed under a microscope. In this method, the preparation of specimens for microscopic examination and the test itself require much time and labor. Furthermore, there is an uncertainty factor involved because a sampling method is used. In contrast, the C-scan UT method, in which flaw detection and recording are conducted by the C-scan system after 96-h immersion, provides the following many advantages:

(1) The HIC propagation on the whole specimen surface is detected in the form of two-dimensional images.
(2) The HIC ratio can be automatically calculated.
(3) A distinction can be made between straight cracking and stepwise cracking.
(4) The required test time is very short.
(5) It is possible to continuously observe the propagation condition of cracks.
(6) This is a nondestructive method.

Figure 7 shows the relationship between the ratio of crack length (%) obtained by microscopic examination and the ratio of crack area (%) obtained by the C-scan UT method. A good correlation is observed, and it is found that these test methods are equivalent. Results of a continuous observation of the propagation behavior of HIC are shown in **Fig. 8**. The specimen was placed in a special test imersion tank in such a manner that one side was in contact with synthetic seawater saturated with H_2S and the other side, in contact with ordinary water for C-scan UT. Clear two-dimensional images reveal how cracks, none of which existed before the immersion, were initiated and progressed day by day. This type of observation was possible because of the nondestructive nature of the method. Thus, this method proved to be a tool very effective for the study of the progressive behavior of cracks. Incidentally, this study also revealed that stepwise cracking occurs when the ratio of crack area, as measured by C-scan UT, exceeds 20%.

Based on the above-mentioned data, this system was adopted at the Kawasaki Steel's Works as the standard means of observation in HIC test and has shown highly consistent results, without operational problems.

Table 2 HIC test procedure

Item	Condition
Test solution	Synthetic sea water (ASTM D1141)
Temperature	25 ± 3°C
H_2S concentration	2 300 — 3 500 ppm
pH	5.1 — 5.4
Test period	96 h

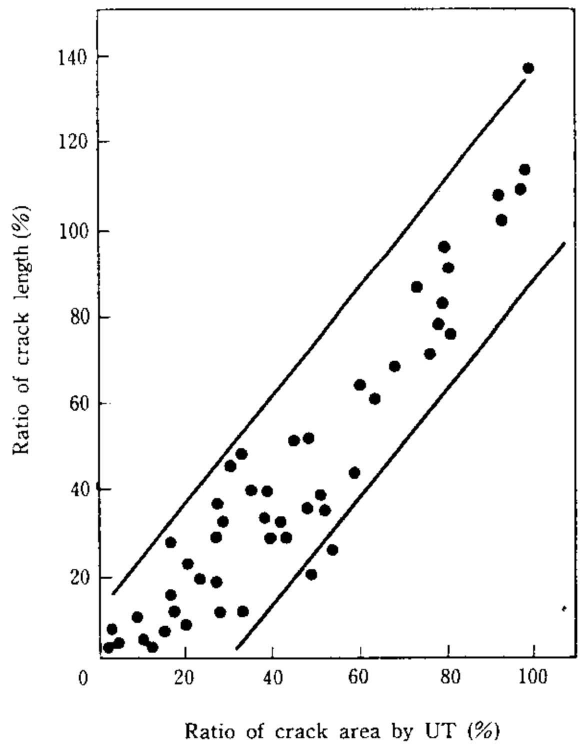


Fig. 7 Relation between ratio of crack length in cross sections of specimen obtained by microscope and ratio of crack area obtained by UT

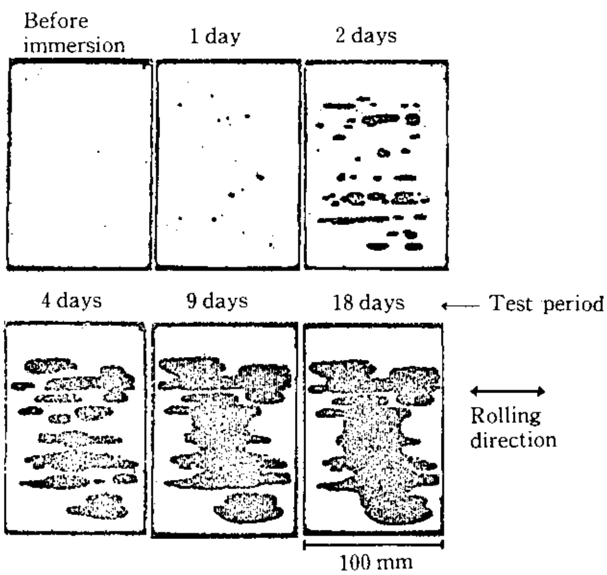


Fig. 8 Propagation behavior of hydrogen induced cracks observed by immersing one side of the specimen in the synthetic sea water saturated with H_2S and detecting cracks from the other side by the C-scan UT

3.2 Application to the Study of Disbonding of Overlay Welds[3,4)]

To assure corrosion resistance, austenitic stainless steel is often overlay-welded on the inside of pressure vessels in chemical plants, such as direct desulfurization units for oil refining, where operation is conducted at high temperature and in high pressure hydrogen atmosphere. Disbonding is sometimes observed near the interface between the base metal and weld metal after long term service in such severe conditions. The hydrogen absorbed through the overlay weld into the internal wall of the vessel contributes greatly to this phenomenon. It is considered that disbonding is induced by the residual stress generated by the cooling at shut down and the hydrogen which, during operation, is occluded into the wall of the pressure vessel through the weld overlay on the inner wall and accumulates abnormally at the interface between base metal and weld metal during such down.

Since the equipment operates in a high temperature and high pressure hydrogen atmosphere, the disbonding poses the danger of explosion and consequent major disaster. For this reason, it is important to establish techniques for predicting and measures for preventing disbonding.

When portions where disbonding is detected by the C-scan system are machined out and the microstructure is examined, it is found that disbonding often seems to be initiated from the carbide precipitation layer formed during post weld heat-treatment which exists along the fusion line in the transition zone between the base metal and the weld metal. It is also often observed that disbonding propagates along the austenite coarse grain boundary on the weld metal side, which seem to grow epitaxially against the prior austenite grains of the base metal (Photo 3).

It is possible to predict the danger of disbonding and to take preventive measures if a point at which the cracking is easily propagate along the austenite coarse grain boundaries can be detected in advance in a nondestructive manner.

"Non-treated" in **Fig. 9** denote C-scope images of a specimen not subjected to high-temperature and high-pressure hydrogen conditions (an as-stress relieved specimen) obtained at two levels of detection sensitivity. The C-scan images shown on the lower portion of the figure were obtained from a standard specimen with flat-bottom holes (artificial flaws) at the weld interface drilled from the overlay side to evaluate quantitatively detection sensitivity. Sensitivity B is 17 dB higher than the sensitivity A. As is apparent from the figure, an image appears in the weld-overlayed specimen at sensitivity B. As a result of a microscopic examination, it was found that this image corresponds to the part of weld

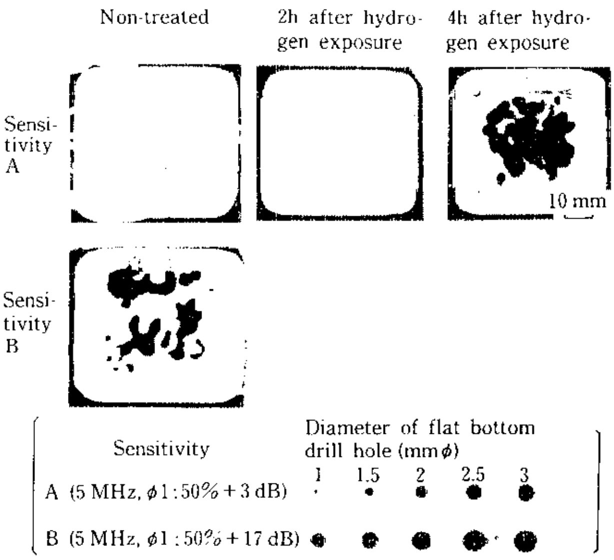


Fig. 9 Influence of pseudo flaw and disbonding

where there exist coarse grains and/or irregular parts at the weld interface. In the following, this image is called the suspected flaw.

A specimen with such suspected flaws was placed in an autoclave at a partial pressure of hydrogen of 150 kgf/cm^2 and a temperature of 455°C and was held there for 48 hours. The specimen was taken out of the autoclave and then cooled by chilled air. Flaw detection was conducted at sensitivity A. The result is shown on the right side of the image of the non-treated specimen. In the figure, 2 h and 4 h show time elapsed after the specimen was taken from the autoclave. **Photo 3** shows the cross section of the area with artificial flaws detected after 4 h. It is apparent that the flaw image given in Fig. 9 is due to disbonding. A comparison between the image of the nontreated material and that of the specimen in which disbonding was caused reveals that disbonding is initiated from a location where a suspected flaw exists, and it is suggested that a correlation exists between disbonding and suspected flaws. Based on the knowledge that the formation of coarse austenite grains depends on the δ-ferrite content of weld metal (the δ-ferrite content on the austenite-martensite boundary line, A-M line, in the Delong-Schaeffer diagram) and that the formation of coarse austenite grains is suppressed when the δ-ferrite content on A-M line is 5% or more, a disbonding test was conducted on specimens with various δ-ferrite contents using an autoclave in order to verify the existence of the correlation mentioned above. The correspondence between the susceptibility to disbonding and the degree of suspected flaws was determined by the C-scan UT method. The result is shown in **Fig. 10**. It is seen clearly that the larger the suspected flaw area, the higher the susceptibility to disbonding.

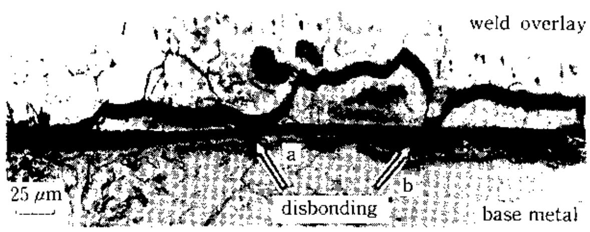


Photo 3 Microstructure and disbonding observed in the transition zone between overlay weld metal of 2 ¼ Cr-1 Mo steel

Consequenty it may be said that susceptibility to disbonding of post-weld heat treated materials can be predicted. This possibility has been ascertained by tests using the C-scan UT system.

3.3 Flaw Detection of Steel Sheets[5]

The pulse echo technique used in usual C-scan ultrasonic testing is often unsuitable for flaw detection of materials of small thicknesses, such as steel sheets. This is because flaws immediately under the surface cannot be identified due to reverberating echoes reflected at the surface (surface echoes). A method of determining the level of bottom echoes, called the echo loss method, is suitable for this application. If a flaw exists in the traveling path of ultrasonic waves, the energy that reaches the bottom side decreases due to scattering and absorption at the flaw. As a result, the level of bottom echoes reflected and received in flaw areas is lower than that in sound parts. In this method, therefore, flaws in sheets are detected by observing the echo level. This is an effective flaw detection method; however, this method is applied only to flat materials with both surfaces kept clean because it is suceptible to effects of microcracks on the bottom side, inclination of sheet, bends, cambers, etc., as compared to the method in which echoes reflected from flaws are directly detected. Therefore, the C-scan system has not been as widely applied to sheets as to plates. A method called double-sound transmission is effective in compensating for this shortcoming.

The principle of double-sound transmission immersion is shown in **Fig. 11**. Some of the ultrasonic waves sent from the ultrasonic probe are reflected by a reflector on the bottom side of the specimen and echoes traverse the specimen twice (R-echoes). Since the scattering and absorption of ultrasonic waves occurs twice in a flaw, the reflected echo in the flaw area is greatly attenuated in comparison with that in sound parts. This phenomenon is utilized in this method. The authors use a mirror-finished type 304 stainless steel plate 20 mm in thickness as the reflector.

As mentioned above, the ordinary C-scan system can be used as is, employing one probe, although this is a

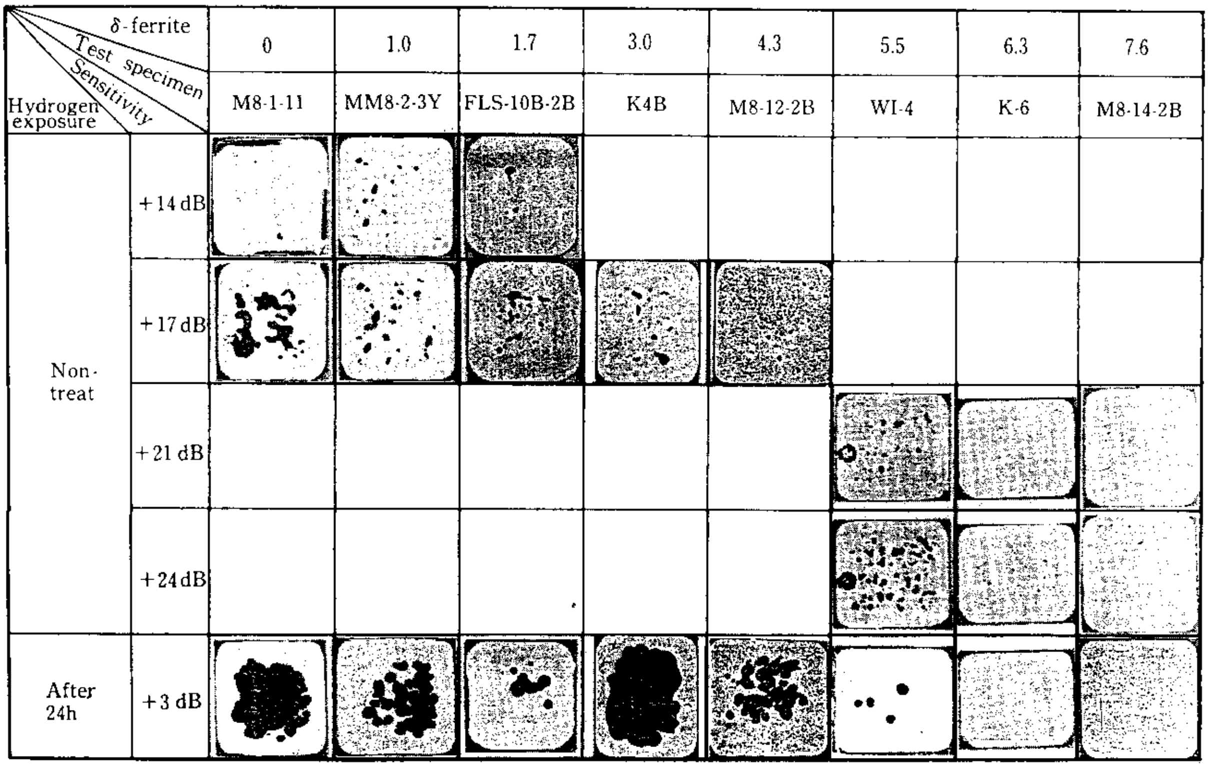


Fig. 10 Influence of δ-ferrite content in weld metal upon disbonding

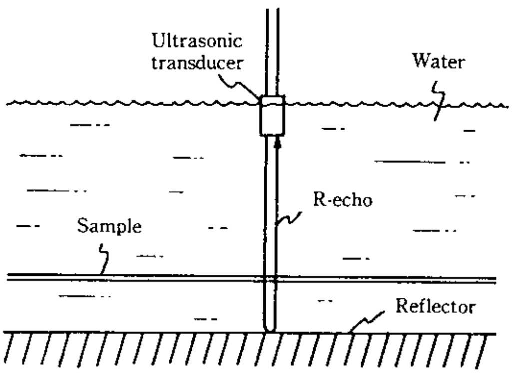


Fig. 11 Schematic of double-sound transmission immersion test

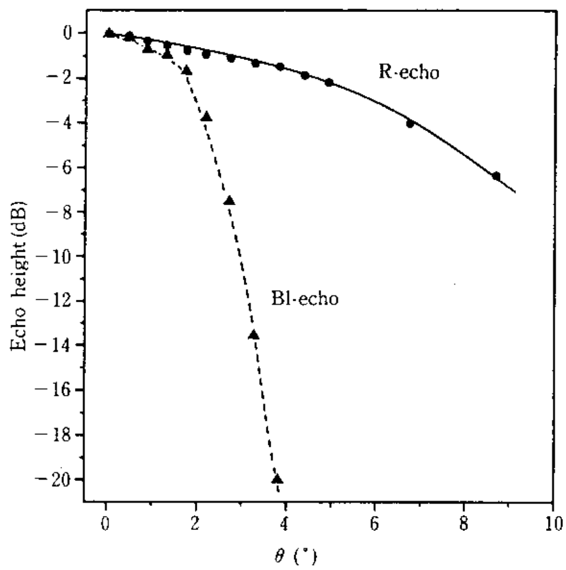
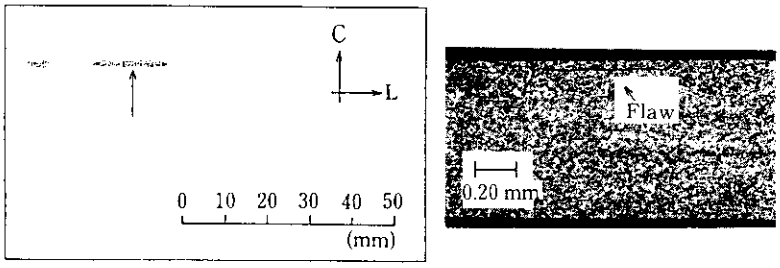


Fig. 12 Relation between echo height and inclination angle of sample

through-transmission method. Furthermore, this method is less susceptible to the effect of bends and cambers of test materials, similarly to the conventional through-transmission method. **Figure 12** shows changes in the level of the first bottom echo (B1-echo) and R-echo as a function of the inclination of the steel sheet sample and ultrasonic beam. It is apparent that the B1-echo attenuates abruptly at an inclination angle of 2° or more, showing the limits of the pulse echo technique.

An example of flaw detection with a sheet is shown in **Fig. 13**. Figure 13(a) shows a C-scope map of a coldrolled type 430 stainless steel sheet 0.69 mm in thickness, in which is indicated an inclusion-induced flaw. Figure 13 is a micrograph of this flaw. In this example, R-echo atte-



(a) C-scope map of stainless steel cold-rolled sheet

(b) Flaw observed under microscope in the cross-section at the arrow-pointed position in (a)

Fig. 13 Example of double-sound transmission UT

nuation, which is 4.5 dB or more larger than in sound areas, was recorded indicating the flaw.

3.4 Flaw Detection with New Materials

In recent years, immersion type ultrasonic scanning flaw detection techniques have also been used in Japan for flaw detection of internal defects and defects in bonded parts of new materials and new functional materials in addition to flaw detection of internal defects and weld defects of metals including steels.[6] An example is the application to the quality evaluation of honeycomb materials, which are structural materials possessing high strength in spite of their light weight, used as airplane members. In a honeycomb structure, a honeycomb core material is sandwiched between skin materials, such as FRP. Main defects of honeycomb materials are lamination of the skin materials, disbonding between the skin materials and core, and failure of the core material. The development of automatic, precision flaw detection techniques for such defects is now under way. The pulse echo technique cannot meet all requirements for flaw detection in such materials, in view of the structure of the materials; the through-transmission method shown in **Fig. 14** is an effective alternative. In this method, the specimen is placed between two probes. By using one probe as a transmitter and the other as a receiver, flaws are detected based on the intensity of the energy of the ultrasonic waves which penetrate the specimen. As shown in **Photo 4**, water squirters are installed before the probes and acoustic coupling with the specimen is provided by the water jets from these squirters. **Figure 15** shows flaw records using a pair of probes when the specimen surface was covered with water jets from the squirters. The specimen was obtained by making artificial flaws in a honeycomb structure of a NOMEX core material sandwiched between skins of CFRP (carbon FRP). The image in Fig. 15 (a) was obtained by detection at normal sensitivity. In (b), the image of the honeycomb structure was intentionally obtained by increasing the sensitivity by about 6 dB. This C-scan system for honeycomb materials is

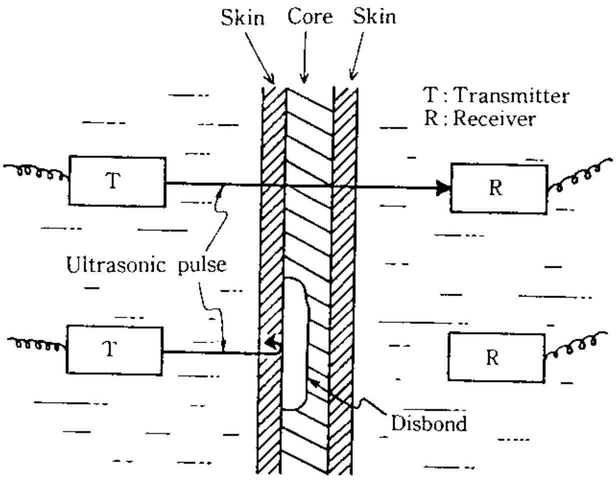


Fig. 14 Schematic of through-transmission method for honeycomb structure

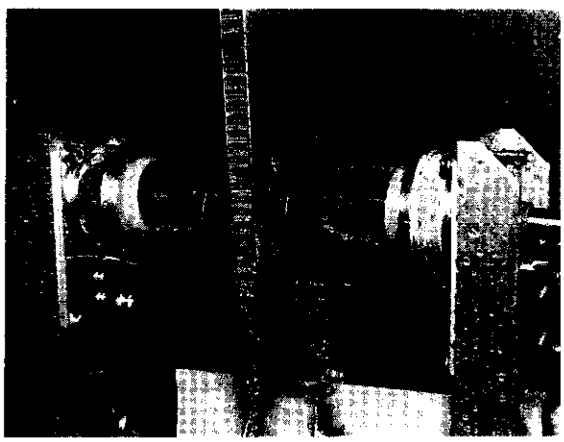
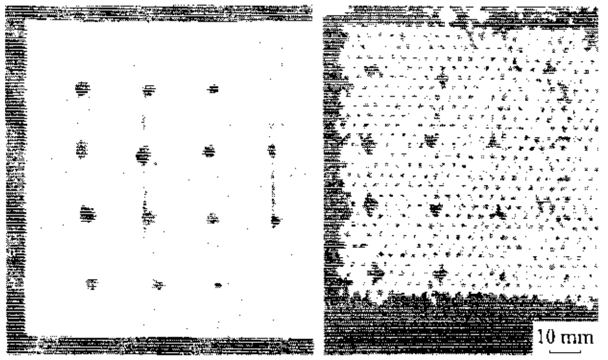


Photo 4 Through-transmission UT by double water squirters



(a) Detected with normal sensitivity (b) Detected with sensitivity of +6 dB

Fig. 15 C-scope records for honeycomb structure (CFRP skins and NOMEX core)

presently under development. The effectiveness of this system in flaw detection with ceramics, CFRP, FRM (fiber reinforced metal), and other materials has already been confirmed as far as flaws on the order of tens of microns are concerned. This system has already been put into practical use by several users.

4 Conclusions

The immersion type ultrasonic scanning flaw detection system developed jointly by Kawasaki Steel Corp. and Kawatetsu Instruments Co., Ltd., has been described.

(1) This system features the use of a high-sensitivity flaw detector, a precision six-axis scanning mechanism, and a sophisticated data processing mechanism employing a microcomputer.

(2) In addition to the simple two-dimensional map recording of flaws, the system has the functions of B-scope recording, the computation and recording of the ratio of flaw area, and computer graphic processing, such as three-dimensional display of flaws.

(3) This system has been applied, with good results, to the detection of cracks in the hydrogen-induced cracking test, disbonding of overlay stainless clad steels, and fine nonmetallic inclusions in ultrathin steel sheets.

This immersion type ultrasonic scanning flaw detection system can be used as a detector for internal defects in metallic materials including steels, for research purposes, for quality assurance tests, and for data feedback to production facilities as a means in the production process itself of preventing flaws. Techniques for these uses are virtually established, and the system has been put into practical use. In recent years, this system has begun to be used for detecting internal defects in new materials and new functional materials, including honeycomb materials for airplane members. It appears likely that higher sensitivity and higher precision in scanning will be required in the future, for example, for the detection of micro-flaws in fine ceramics. Furthermore, the size of the system will increase and the method of scanning will become more complex as it is applied to airplane members, etc. The authors intend to continue with positive efforts towards the development of ultrasonic flaw detection methods suitable for various materials and shapes, free-curvature tracking control techniques, and data processing techniques based upon evaluation of the severity of detected flaws.

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