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UT CHARACTERISTICS FOR DETECTABILITY OF DEFECTS FOR INCONEL WELD

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1. ABSTRACT

Toshiba, Hitachi and GE are jointly constructing advanced boiling water reactors (ABWRs) unit 6 and 7 at Kashiwazaki Kariwa Nuclear Power Plant site, Tokyo Electric Power Co.

The ABWRs feature enhanced operability and safety as a whole plant through simplicity and improved performance. To achieve this simplicity, ten reactor internal pumps (RIPs) are introduced as the reactor recirculation system.

The RIP casing to hold the RIP and constitute the primary pressure boundary together with RPV is welded to the nozzle on the RPV lower shell by Gas Tungsten Arc Welding (GTAW).

In consideration of the importance of this welded joint (being primary pressure boundary), we planed to carry out ultrasonic examination (UT) in ISI.

This paper summarizes the experiments which were carried out to study the detectability of UT for the Inconel weld according to the above plan.

2. INTRODUCTION

The structure of the welds on the RIP casing and nozzle is shown in the figures below.

An 18 mm gap is provided between the RIP casing and the skirt to provide access to inspecting surfaces for various inspecting devices.

We will use this gap to carry out remote controlled UT in ISI.

The low alloy steels of the RIP casing and the RPV are buttered with Inconel filler metal, followed by butt welding on the V-groove using the automatic GTAW technique from inside.

It is well known that the UT for Inconel welds is as difficult as for austenitic stainless steel welds because of ultrasonic attenuation and generation of spurious echoes, etc. For these reasons, we performed experiments to study UT detectability of the relevant Inconel welds.

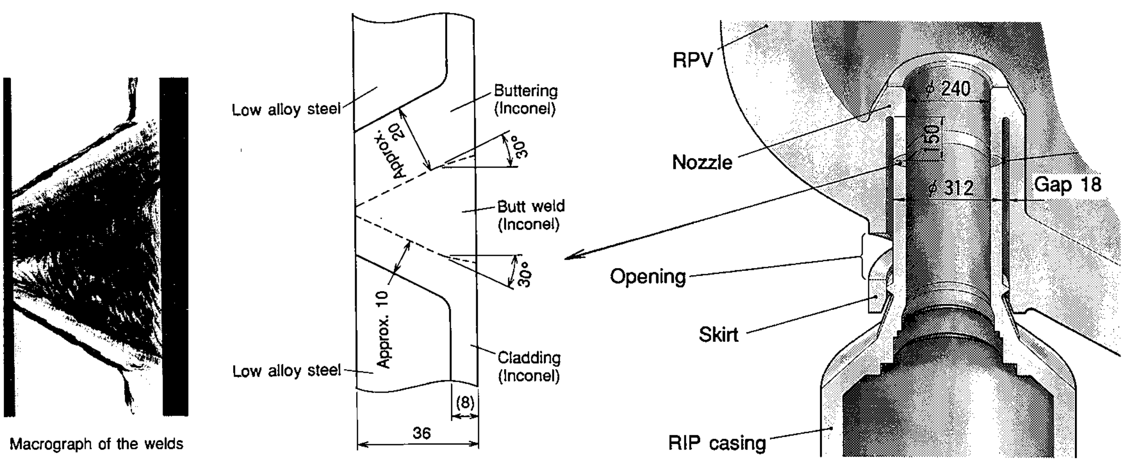


Figure 1 Structure of the Relevant Area

3. TECHNICAL DISCUSSION

The angle beam technique of the longitudinal wave mode is an effective flaw detecting method for parts to which it is difficult to apply angle beam technique of the ordinary shear wave mode (such as Inconel welds).

However, in the case of the angle beam technique of the longitudinal wave, mode transformation inevitably occurs in wave propagation, and for this reason, the effective detecting range is limited to the range of beam path which is shorter than 4/8V path, with the result that the dead zone of ultrasonic waves near the sound entry point (subsurface of the material on the probe side) may become a undetectable zone.

Here, confirmation of UT detectability of Inconel welds is performed using dual element T-R type 45° angle beam probe emitting longitudinal waves.

In addition, we confirmed by testing applicability of the other two UT methods for subsurface examination to cover the undetectable zone mentioned above.

They are creeping wave technique and immersion technique. Explanation of the former is omitted because it is well known. In the immersion technique in this experiment, as shown in Fig. 2, ultrasonic waves are transmitted to the material through water at an angle, and the surface flaw is detected by the surface waves generated on material surface and by scattering waves directly reflected from the tip of a surface flaw.

Surface waves lose their energy because of leaky waves in the water, and for this reason, a flaw is detected, when the sound entry point is close to the flaw.

This technique is hereafter referred to as water gap technique.

Results of the respective experiment and problems (phenomena) encountered in these UTs are reported below.

4. MATERIALS USED IN EXPERIMENTS

Specifications of the probes used in respective experiment are shown in the table 1. Test specimens used for detectability confirmation were manufactured using similar materials, weld and configuration to those of actual components. Test specimens used for studying influence of surface roughness on UT were made of stainless steel plates.

And artificial flaws with several depths were carved on test specimens with circular saw 20 mm in diameter.

Table 1 Specification of Probes

Technique	Angle of Refraction (°)	Wave Mode	Frequency (MHz)	Element (mm)
Angle Beam	45	Longitudinal	3	10×10 (Dual)
Water Gap	90 (70*)	Surface (Shear*)	5	5×10 (Single)
Creeping Wave	90	Longitudinal	5	10×10 (Dual)

*Main Beam in Material

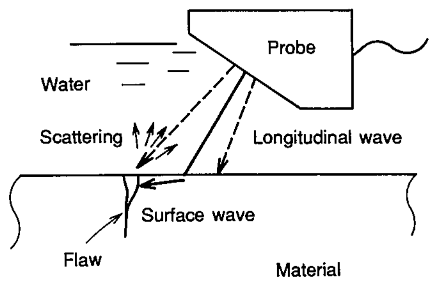


Figure 2 Principle of The Water Gap Technique

5. EXPERIMENTAL RESULTS

5. 1 Longitudinal Wave Angle Beam Technique

The relevant inspection areas consist of a combination of buttering and butt weld, and for this reason, the areas have the structural feature that the Inconel deposited metal range is wider in the length direction than those of ordinary weld joints. We therefore conducted a test corresponding to this structural feature.

In concrete, relationship between location of flaw (whose location was shifted in the length direction) and flaw detectability was examined.

First, DAC curve was constructed according to the ASME system. Next, each artificial flaw was detected to compare the detect level.

The results are shown in Fig. 3. As shown in the figure, the pulse amplitude varies significantly depending on the location of the flaw. Similar tendency was observed for both scanning directions though the level of change differs.

This is because (1) the different propagation paths through the deposited metal caused different ultrasonic attenuation, eventually affecting the flaw detectability, and (2) the angle between the ultrasonic beam direction and the growth direction of dendrite affected ultrasonic attenuation.

These two points were confirmed in the experiments described below.

a. Relationship between Pulse Amplitude and Attenuation

Wave propagation path and variable ultrasonic attenuation were studied using the part of the test specimen with which the relationship between location of flaw and flaw detectability was tested.

A through-transmission technique was employed where a pair of 45° angle beam probes of longitudinal waves were so arranged as to correspond to the positional relationship between flaw and the probe which brought about the results shown in Fig. 3.

Ultrasonic waves were emitted from one side (outside) of the test specimen with a certain sensitivity, and the waves which transmitted the test specimen were received on the opposite side (inside).

Relative level of change in the received pulse amplitude which is considered change in attenuation is recorded. When we overlay this result on the Fig. 3, we obtain Fig. 4. These two relations have a good coincidence.

Thus, the results of the test indicate that variable pulse amplitudes with the location of flaws is the direct representation of different attenuation on respective paths.

b. Relationship between Growth Direction of Dendrite and Attenuation

As general tendency, pulse amplitude decreases, or attenuation increases, when an ultrasonic propagation path extends through the deposited metal for a long distance. There are, however, some peculiarities.

This appears to be because the level of attenuation by deposited metal is partly nonuniform over a given ultrasonic propagation path.

The major metallurgical factor of deposited metal that affects the ultrasonic attenuation appears to be the growth direction of dendrite as reported in some other papers on the weld of austenitic stainless steels.

To confirm this point for Inconel weld, a bar 18 mm in diameter was cut from the Inconel butt weld which simulated the actual component in such a manner that the dendrite direction was approximately unidirectional.

We quantitatively confirmed the change in ultrasonic attenuation when the ultrasonic beam direction was set at an angle to the bar. A pair of normal probes were used in the test.

The bar was rotated in the water while ultrasonic waves were transmitted from one side of the bar, and received on the 180° opposite side.

Relative level of the received pulse amplitude is plotted in Fig. 5.

It is evident from the figure that attenuation of longitudinal wave varies greatly with the angle between the direction of incidence of ultrasonic beam and the growth direction of dendrite.

A large attenuation was observed when the growth direction of dendrite agrees with the ultrasonic beam direction. Attenuation decreases in the approximately 45° direction.

This phenomenon was repeated at the 90-degree cycle. The difference of attenuation is 6.8 dB maximum.

This suggests that the change in pulse amplitude corresponding to the location of flaw shown in Fig. 3 is quite probable for the Inconel weld.

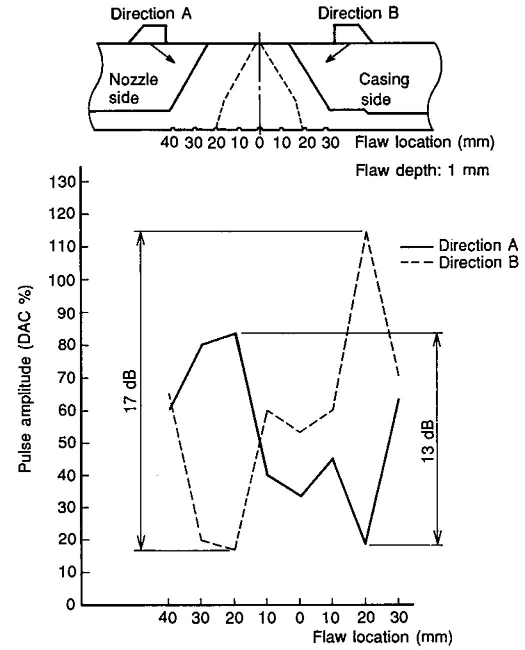
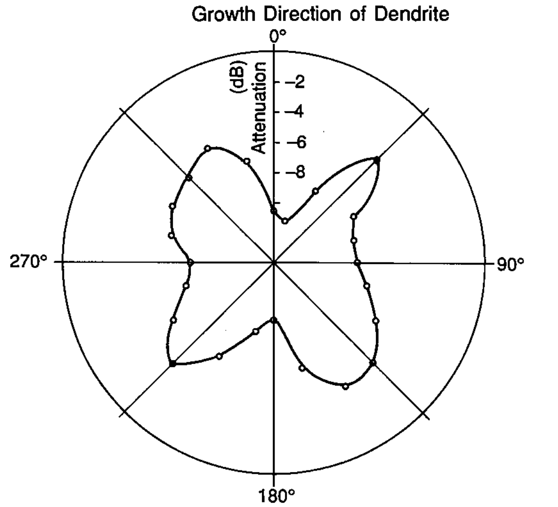


Figure 3 Flaw Detectability Corresponding to Flaw Location (Longitudinal Wave Angle Beam)



Note 1: The carbon steel bar 18 mm in diameter was used to establish the reference level (0 dB)

Figure 5 Growth Direction of Dendrite and Attenuation of Longitudinal Wave

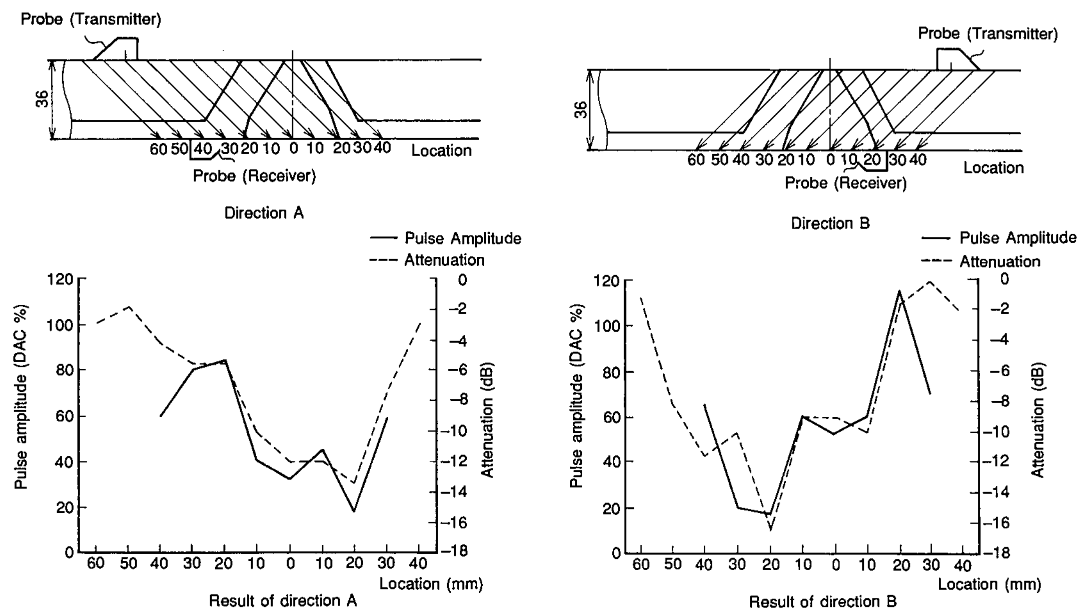


Figure 4 Pulse Amplitude and Attenuation (Longitudinal Wave Angle Beam)

5. 2 Other Techniques for Subsurface

5. 2. 1 Water Gap Technique

A notch on the surface of Inconel butt weld and a fatigue crack on a stainless steel plate were detected on condition that the water path was 10 mm.

As shown in Fig. 6, because the sound entry point is close to the flaw in this method, influence of attenuation by materials is small, and it is confirmed that the system has a high detectability for surface flaws of the weld.

However, as shown in Fig. 7, it is found that surface scattering noise becomes prominent if the detecting surface is rougher than approximately 13 μm Rmax, and may possibly interfere with flaw echoes.

Further, it is confirmed that because effective surface waves penetrate the material only for a small distance, the pulse amplitude for a flaw rarely changes for variable flaw depths, easily saturating at shallow flaws, and thus the pulse amplitude can not be used as an indication of the size (depth) of a flaw.

5. 2. 2 Creeping Wave Technique

The creeping wave technique is less sensitive than the water gap technique, but as shown in Fig. 8, it was effective for detecting notches 1, 2 and 4 mm deep in the weld. It is also found that for surface roughness of approximately 20 μm Rmax or finer (better), generation of spurious echoes and decreased flaw pulse amplitude do not present a problem.

This was confirmed by the test to detect notches on a stainless steel plate machined to variable surface roughness as shown in Fig. 9.

Effective penetration of ultrasonic waves into materials was also confirmed.

The result is shown in Fig. 10.

This result indicates that although the detect sensitivity varies with the location of flaws in the depth direction, the detecting range is not limited to surface but covers subsurface as well.

6. CONCLUSION

Basic data of UT for inconel weld were obtained as described above. These basic data indicate that for the angle beam technique of longitudinal waves, the relationship between the location of a flaw and detectability must be taken into consideration when evaluating indications because pulse amplitude varies greatly with the location of flaw.

Further, comparison of the above two types of techniques indicates that in the subsurface examination, the immersion technique for surface flaw has a high sensitivity, but as mentioned before, the method has several shortcomings.

We therefore judge that it is better to use the surer method, creeping wave technique.

Accordingly we will perform UT in ISI by combining two types of techniques, longitudinal angle beam waves and creeping wave technique.

7. ACKNOWLEDGEMENT

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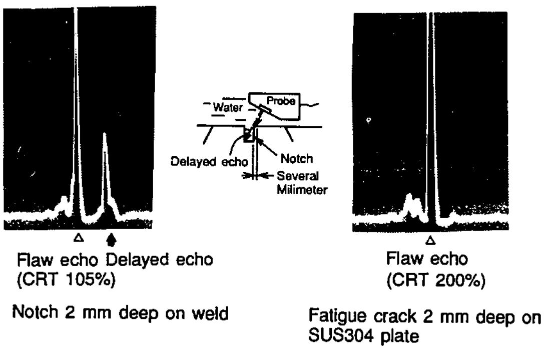
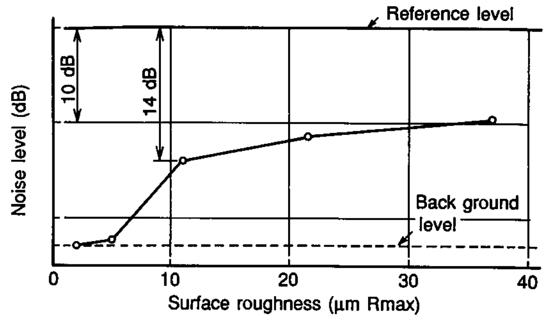


Figure 6 Oscilograms of Reflection from Surface Flaws (Water Gap)



Note 1: The notch 4 mm deep on the weld was used to establish the reference level

Figure 7 Scattering Noise Caused by Surface Roughness (Water Gap)

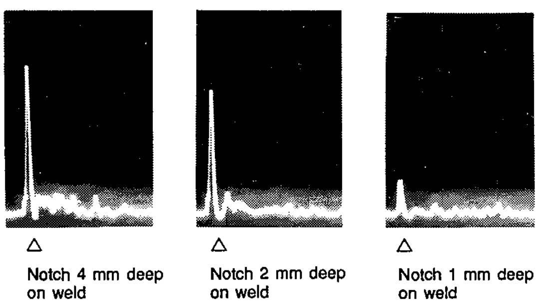
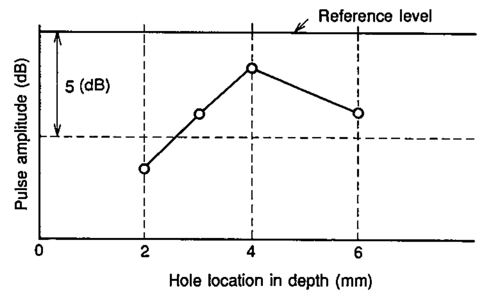


Figure 8 Oscilograms of Reflection from Surface Flaws (Creeping Wave)



Note 1: The notch 4 mm deep on the weld was used to establish the reference level
Note 2: Side drilled holes 3.2 mm in diameter at variable depth in the weld were used for the test

Figure 10 Sensitivity Distribution in Subsurface (Creeping Wave)

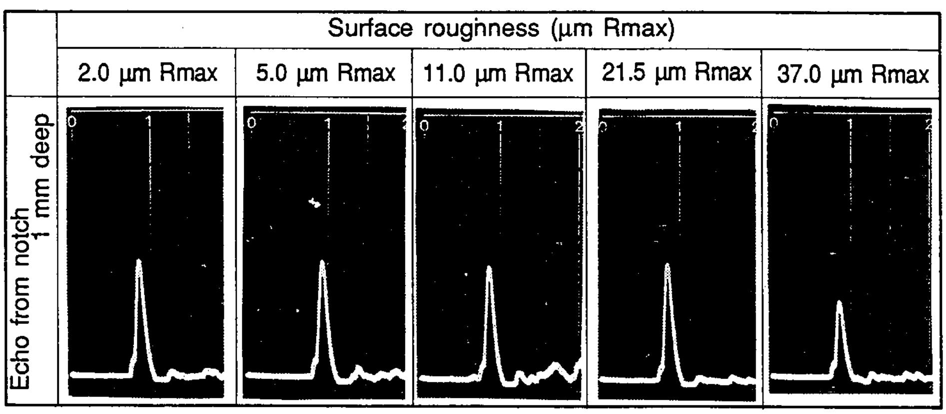


Figure 9 Influence of Surface Roughness on Detectability (Creeping Wave)