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Nonlinear Ultrasonic Technique for Evaluating Degradation of Dissimilar metal welds in Nuclear Facilities

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Abstract

This study presents the nonlinear ultrasonic technique to evaluate structure health of nuclear facilities. Recently, a dissimilar welds cracking in the aging of nuclear power plant has become a big issue. For this reason, this study was performed for dissimilar welds composed of SA508 cl.3 low alloy steel, Inconel 82 weld, and AISI 316L stainless steel damaged by high temperature long-term aging. Structure health was evaluated through the measurement of nonlinear ultrasonic characteristic. Microstructural changes of material have an effect on nonlinear ultrasonic characteristic and generate second harmonics that is twice the fundamental frequency. Ultrasonic oblique incidence measurement technique was used to measure ultrasonic nonlinearity.

Keyword : Nonlinear ultrasonic(NLU), dissimilar metal welds, nuclear facilities, oblique incidence technique

1. Introduction

In the nuclear power plant industry, various components or systems operate under different service conditions and, hence, appropriate materials should be selected for each component or system. Therefore, dissimilar weld metal joints are inevitably required to link the components or systems made of different materials. Dissimilar metal welds between stainless steel piping and low alloy steel nozzles are used in reactor pressurized vessels (RPV) in the primary system of nuclear power plants. In pressurized reactors, cracks have been reported in nozzles, both in the base metals and welds, due to material degradation such as thermal aging, corrosion and fatigue [1,2]. Material degradation shortens the lifespan of plant facility components under high temperature, and can lead to large-scale disasters due to sudden failures. The damages to the structures at nuclear power plants could possibly be the cause of a radiation leak. Therefore, safety evaluation or life assessment of such structures is considerably important and necessary.

In recent, nonlinear ultrasonic have been reported to be highly sensitive to microstructural evolutions. When an ultrasonic sinusoidal wave of a given frequency is introduced into a solid material, the ultrasonic waveform propagating through the material responds to the stress-strain relationship. If the incident amplitude of the ultrasonic wave is high, it results in plastic modifications of the material, and the incident waveform may be distorted as it propagates due to lattice anharmonicity. Consequently, second- and higher-order harmonics of the fundamental frequency will be generated. Nonlinear ultrasonic technique have been studied in many physical, mechanical and material research areas for characterization of material degradation [3,4].

Physically, this wave distortion arises because of a deviation from the elastic behavior of material, which is related with stress-strain in the solid. This relationship between stress (σ) and strain (ε) is not linear. It is expressed as $\sigma = E\varepsilon\,(1-\beta\varepsilon + \cdots)$, where E is modulus, β is parameter indicating the amount of material nonlinearity. The acoustic nonlinearity parameter may be obtained from measurements of the displacement of the fundamental acoustic wave and the second harmonic wave. The second order nonlinearity parameter β is determined as follows [5].

$$\beta = \frac{8A_2}{A_1^2 k^2 x}\,. \tag{1}$$

where A_1 is the displacement of the fundamental wave, x is the propagation distance of ultrasonic wave. For the second harmonic wave, A_2 is $(\beta A_1^2 k^2 x)/8$, k is the propagation constant, $2\pi/\lambda$ (λ is the wavelength).

In the present study we assessed the thermal degradation (long-term aging) of dissimilar metal welds and stainless steel subjected to high cycle fatigue by acoustic nonlinearity.

2. Experimental procedure

The dissimilar weld metal joint was made after buttering alloy 82 on the SA 508 Cl.3 side by gas tungsten arc welding (GTAW). Accelerated thermal degradation of dissimilar metal welds was performed at 600℃ and interrupted at several predetermined times to observe different levels of damage.

A high-power gate amplifier was used to provide high-power tone-burst signals to the transmitter. A schematic diagram of the experimental setup for measuring the acoustic nonlinearity of a longitudinal wave with oblique incidence measurement technique is shown in Fig. 1. Transmitting and receiving transducer are placed on the same side of specimen. Transmitting and receiving transducer were attached 45-degree refractive angle wedge. And 1 skip distance was measured as 22 mm. The received signal was digitally processed using fast Fourier transform power spectral analysis in order to obtain the amplitudes of the fundamental and second-order harmonic frequencies.

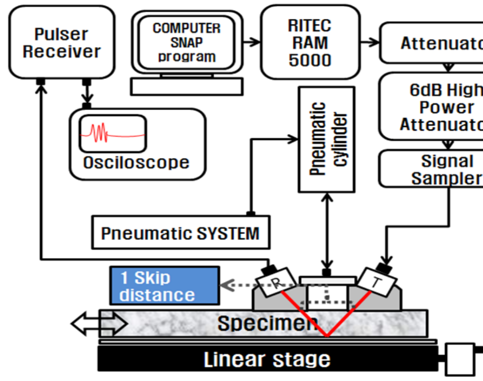
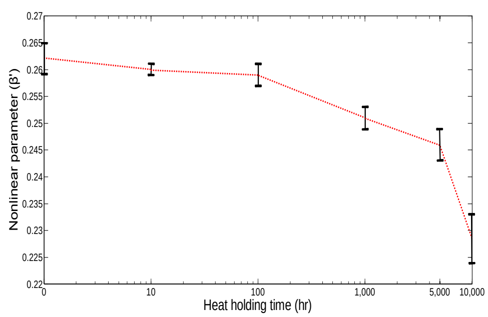


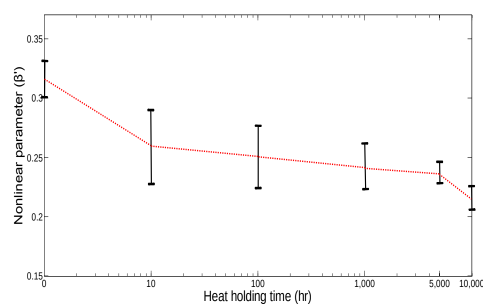
Fig. 1 Schematic diagram of the experimental setup for the measurement of the acoustic nonlinearity by oblique incidence technique

3. Results and Discussion

Figure 2 shows the variation in acoustic nonlinearity as a function of aging time in dissimilar metal welds measured by oblique incidence technique. The acoustic nonlinearity decreased in SA508 cl.3 and AISI 316L as the increase of aging time. But the acoustic nonlinearities in alloy 82 showed large fluctuation as shown in Fig. 2(c) because weld region may contains many irregularities of lattice that influence on wave distortion resulting in acoustic nonlinearity.



(a)



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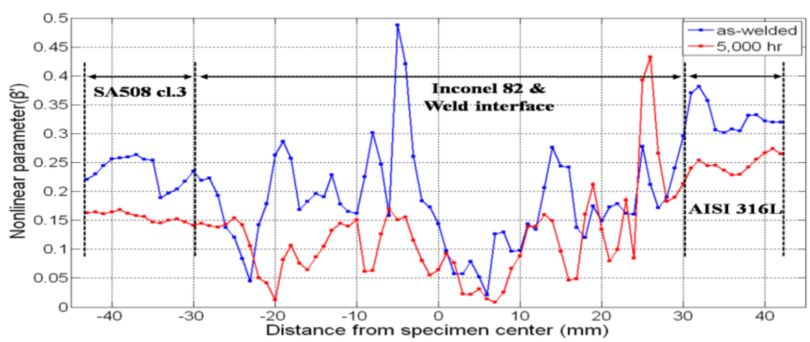

(c)

Fig. 2 Nonlinear parameters as a function of aging time using oblique incidence technique: (a) SA508 cl.3 (b) AISI 316L (c) A comparison of nonlinear parameter between as-welded and 5000 hr heating specimens

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References

[1] R.K. Singh Raman, ‘Role of Microstructural Degradation in the HAZ of 2.25Cr-1Mo Steel Weldments on Sub-scale Features during Steam Oxidation and their Role in Weld Failures’, Metallurgical and Materials Transactions A, Vol. 28 A, pp. 577-581, 1998

[2] A. Joseph, A.S. Ramesh, T. Jatakumar T. and N. Murugan, ‘Failure analysis of a dissimilar weld joint in a steam generator.’ Practical Metallography, Vol. 38(12), pp. 667-679, 2001

[3] J. H. Cantrell, W. T. Yost, ‘Nonlinear ultrasonic characterization of fatigue microstructures’, International Journal of Fatigue, Vol. 23, pp. 487-490, 2001

[4] D. C. Hurley et al., ‘Nonlinear ultrasonic parameter in quenched martensitic steel’, Journal of Applied Physics, Vol. 83[9], pp. 4584-4588, 1998

[5] C S Kim, I K Park, K Y Jhang, ‘Nonlinear ultrasonic characterization of thermal degradation in ferritic 2.25Cr-1Mo steel’, NDT&E International, Vol. 42, pp. 204-209, 2009