Feasibility study for application of nonlinear ultrasonic technique for CASS material

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1. Introduction

Cast Austenitic Stainless Steels (CASS) have been used for piping and components for reactor coolant system (RCS) of pressurized water reactors (PWR) because of their good weld ability, strength and corrosion resistance. Although these advantages, CASS are susceptible to thermal embrittlement caused by long-term operating of PWR.

As the part of nondestructive evaluation, ultrasonic method has been recommended for identifying the volumetric flaw as the way of monitoring the loss of fracture toughness indirectly. However, the CASS have coarse grains and anisotropic microstructure which cause the scattering and attenuation of ultrasonic waves. Because of those characteristics of CASS, it is difficult to ensure the reliability of the ultrasonic test results, and verified procedures and guidelines have not been established [1].

To overcome this limitation of the conventional ultrasonic test, this study evaluates the variation of the mechanical properties of thermally aged CASS using the nonlinear ultrasonic method.

2. Nonlinear Ultrasonic Technique

The nonlinear ultrasonic technique (NUT) has been considered as a potential NDE method for assessing the early damage of material. This technique is based on the nonlinear elastic interaction between a material and a propagating ultrasonic wave.

The nonlinearity parameter, β, is determined from the displacement amplitudes of the fundamental and the second-order harmonic frequency components, as follows [2]:

$$\beta = \frac{8A_2}{A_1^2 k^2 x} \quad (1)$$

where A_1 and A_2 are the fundamental and second-order harmonic displacement amplitudes, k is the wavenumber of the fundamental frequency, and x is the propagation distance. Note that the nonlinearity parameter β is derived for one-dimensional propagation of a longitudinal wave through an isotropic material in which the lateral strain is restrained. It is well known that the parameter β is closely related to the microstructure of a material [3].

3. Specimens and Experiments

3.1 Specimens

We prepared the CF8M specimens. The specimens were provided as annealed at 1050℃ for 4 h followed by water quenching [4]. The specimens were exposed to various aging temperatures (343℃, 375℃, 400℃) and times (5,000 h, 10,000 h, 20,000 h). After the specimens were prepared, the nonlinear ultrasonic measurements were firstly performed, and the hardness test was carried out using a micro-Vickers hardness tester (Shimadzu, HMV-2T).

3.2 Nonlinear Ultrasonic Measurements

The nonlinear ultrasonic measurement was performed in a through-transmission technique as shown in Fig. 1. The transmitter was a PZT transducer with 5 MHz center frequency. An input tone-burst signal with 10 cycles was generated from a high-power gated amplifier (RITEC, RAM-5000 SNAP). The frequency spectrum of the received signal was calculated through a FFT after applying a Hanning window. From the FFT results, the magnitudes of the fundamental and second harmonic frequency components were determined. This process was repeated after increasing the input voltage levels to improve reliability of measurement. Finally, the nonlinearity parameter of each specimen was determined by the amplitude of fundamental and second-order harmonic frequencies.

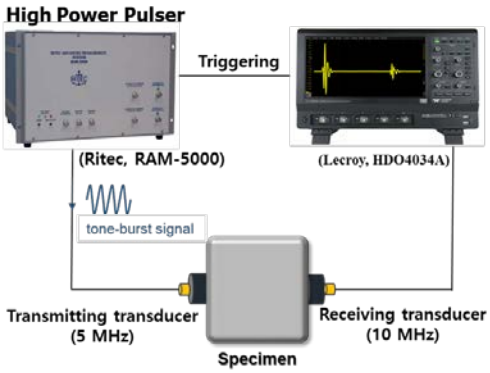

Fig.1 Experimental setup for nonlinear ultrasonic measurement.

3. Results and Conclusions

In this study, we evaluate the correlation between the nonlinearity parameter β and the mechanical property(hardness) related to embrittlement of the thermally aged CASS specimens. Experimental results show that the nonlinearity parameter has a close relationship with the variation of the hardness caused by the thermal aging. From the experimental results, the applicability of nondestructive technique has identified.

Acknowledgement

This research was supported by Nuclear Safety Research Program through the Korea Foundation of Nuclear Safety(KoFONS) funded by the NSSC (No. 1805005) & the Nuclear Power Research and Development Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (NRF-2013M2A2A9043241, NRF-2017M2A8A4015158).

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