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Material Characterization of Zircaloy tubes at Elevated Temperatures Using Laser Ultrasound Technique.

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Abstract

Material properties of Zircaloy cladding can degrade substantially and threaten the fuel integrity while in nuclear reactor service at elevated temperature. Other than radiation exposure, precipitated hydrides are also shown to be responsible for hydrogen embrittlement of the claddings. A laser ultrasound technique (LUT) is used to measure the dispersions of guided waves propagating along the axial direction of the cladding tubes at different temperature environment. It is shown that the LUT is able to measure the dispersion curve of Zircaloy in the elevated temperature environment. The dispersion spectra shift towards the direction of lower frequency and lower velocity while the temperature increase. With the inversion procedure, material properties such as elastic modulus is successfully characterized in various elevated temperature. The Young's modulus is found to decrease linearly as the temperature increasing. This research is focuses on the characterization of material properties, elastic moduli in particular, at elevated temperatures for Zircaloy cladding tubes of various hydrogen concentrations (H.C.).

Keywords: Zircaloy, Laser Ultrasound, Dispersion, High Temperature

1. Introduction

Motivated by various practical applications, researches in the nondestructive characterization of material or geometrical properties of tubes continue to be interested. In nuclear industry, geometrical and material properties of Zircaloy cladding tubes need to be evaluated for the structure integrity of fuel while the fuel are expected to extend their service life for economic operation. It is an important task to measure the material properties of Zircaloy cladding tubes at high temperature environment with an nondestructive method. Guided waves propagating in tubes have been extensively used to characterize properties of tubes. Axially propagating guided waves has been reported to characterize hydrogen concentration in Zircaloys[1]. In this study, axially guided waves are used characterizing cladding tubes with different environment temperature. Guided waves propagating in Zircaloy cladding tube with different environment temperature are measured with Laser ultrasound technique (LUT) which is an nondestructive and non-contact method. A inversion technique based on combining theoretical and experimental study is proposed and illustrated in the following sections.

2. Laser Ultrasound Technique

A laser ultrasound technique (LUT) is used for the measurements of dispersions of guided waves propagating along the cladding tubes. Dispersion relations of guided wave propagating in Zircaloy cladding tubes with 20°C , 50°C, 100°C, 150°C, 200°C, 250°C and 295°C environment temperature are measured with laser ultrasound technique (LUT). **Fig. 1** shows a Zircaloy tube specimen with different hydrogen content.

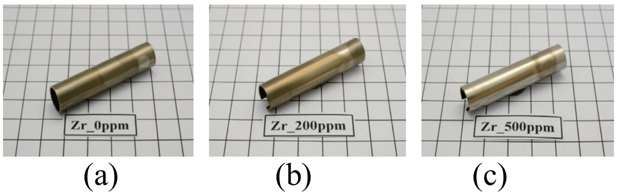

Fig. 1 Zircaloy cladding tube specimen (a) Zr_0ppm (b) Zr_200ppm (c) Zr_500ppm.

As shown in **Fig. 2**, the experimental configuration consisting of a pulsed laser for the generation of ultrasonic waves and a laser-based optical detector for the detection of acoustic waves. A B-scan scheme is used for the measurement of the dispersion behaviors. During scanning, the optical detector is located at a fixed point, while the generation laser beam is scanned along the samples. A two-dimensional fast Fourier transform (2D-FFT), first taken with respect to time and then with respect to the scanned position, is used to obtain the dispersion relation from the B-scan data.

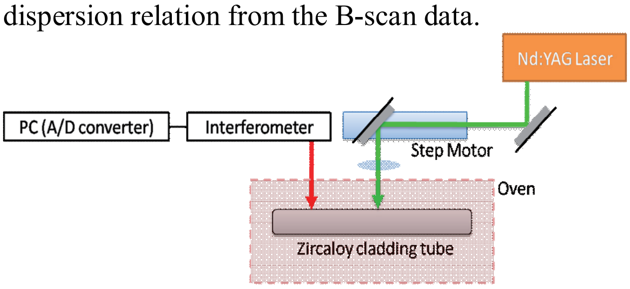

Fig. 2 Experimental configuration of the LUT

3. Inversion method

Following the measurements on the dispersion spectra of guided modes propagating in a tube, an inversion procedure can be employed to obtain properties of the samples. Among many inversion algorisms, simplex method is frequently used together with ultrasound measurements, and is adopted in this research.

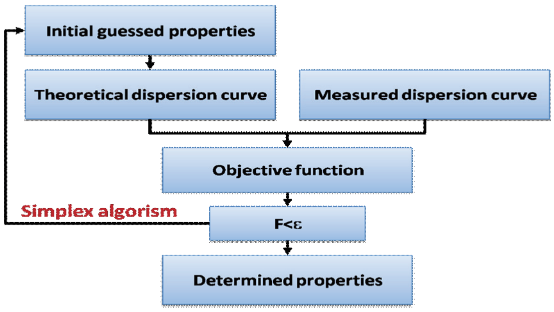

Fig. 3 Experimental configuration.

The procedure using the simplex algorism to extract properties from the measured dispersion spectra is illustrated in a block diagram in **Fig. 3**.

4. Results and Dicussions

Fig. 4&5 shows dispersion curves of Zircaloy cladding tubes with different H.C. in the elevated temperature environment by using LUT. The dispersion spectra shift towards the direction of lower frequency and lower wavenumber while the temperature increase.

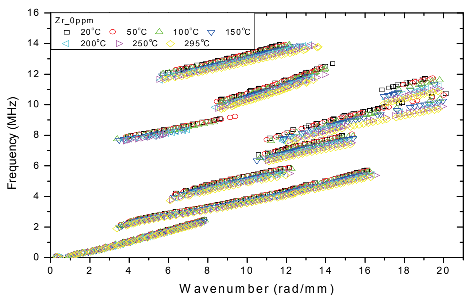

Fig.4 Zr_0ppm

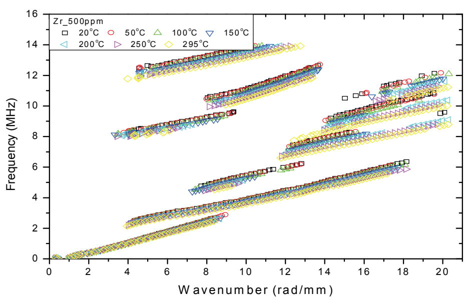

Fig.5 Zr_500ppm

Fig.6 shows inversion result of temperature dependence of Young's modulus for Zr-4 sample and compare with two sets of reference data. This method has proved to good accuracy.

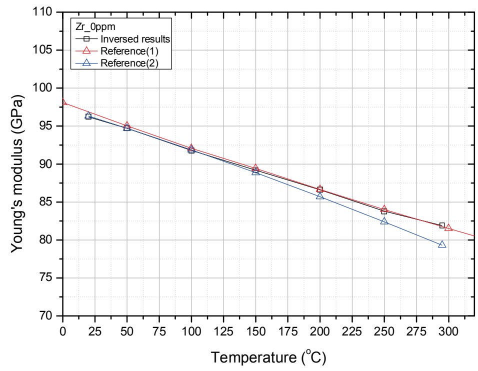

Fig. 6 Measured Young's modulus at elevated temperatures.

4. Conclusions

Zircaloy claddings are constantly operated, and call for characterization of material properties, at elevated temperature environments. The current research is based on a laser ultrasound technique for measuring dispersion spectra of guided waves followed by a simplex-based inversion algorism to extract material property. According to this procedure is able to characterize the temperature in a quantitative way. It is also found out that the elastic modulus decreases as the temperature increases. This research employing LUT and inversion algorism is effective for characterizing the Zircaloy tubes and other structures with their properties calling for determination in elevated temperature environment with a remote and nondestructive way.

Acknowledgment

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