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Material characterization of Zircaloy tubes with Laser ultrasound technique in high temperature environment

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Abstract

This research is focused on characterizing Zircaloy cladding tubes in high temperature environment up to 295°C. A procedure corporate with an experimental technique is used to investigate the effects of high temperature on the dispersion spectra of guided waves. A laser ultrasound technique (LUT) is used to measure the dispersions of guided waves propagating along the axial direction of the cladding tubes in 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 method is potentially useful to probe the material characterization in high temperature environment in a remote and nondestructive way which is desired in nuclear power industry.

Key words: Laser ultrasound, dispersion, guided waves, high temperature, Zircaloy.

1. Introduction

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. Zircaloy cladding tubes usually lie in high temperature environment. It is an important task to measure the material properties of Zircaloy cladding tubes in high temperature environment with an noncontact 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. A inversion technique based on combining theoretical and experimental study is proposed and illustrated in the following sections.

Fig. 1 Zircaloy cladding tube

2. Laser Ultrasound measurements

Dispersion relations of guided wave propagating in Zircaloy cladding tube with 20°C , 50°C, 100°C, 150°C, 200°C, 250°C and 295°C environment temperature are measured with a laser-generation/laser-detection laser ultrasound technique (LUT). The experimental configuration consists of a pulsed Nd:YAG laser for generation of guided waves and a laser interferometer for detection. Laser beam scans along the axially direction in the tube by step motor combine with mirror set and an oven control the environment temperature, as shown in **Fig. 2**.

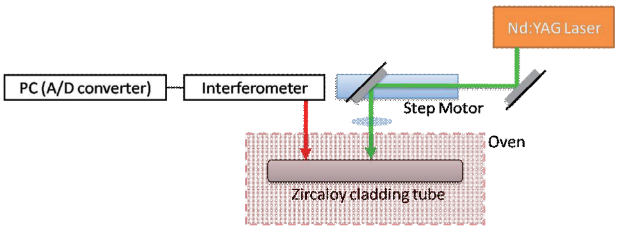

Fig. 2 Experimental configuration of the LUT

3. Inversion with simplex algorism

Following the measurements on the dispersion spectra of axially guided waves propagating in a tube and combine with a theoretical model [2], an inversion procedure can be employed to obtain properties of the samples. The inversion method in this study is based on simplex algorism to extract properties from the measured dispersion spectra is illustrated in a block diagram in **Fig. 3**.

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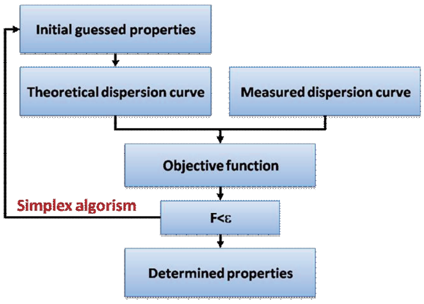

Fig. 3 A flowchart showing the inversion procedure

4. Results and Discussions

Dispersion curves of axially guided wave measured with the LUT are shown in **Fig. 4** for the Zircaloy cladding tube with different environment temperature. The raising of environment temperature influences the dispersion left-offset at higher modes. Measured dispersions are compared with the inversed results in **Fig. 5**, it is shown that the inversed agree with the measurement very well.

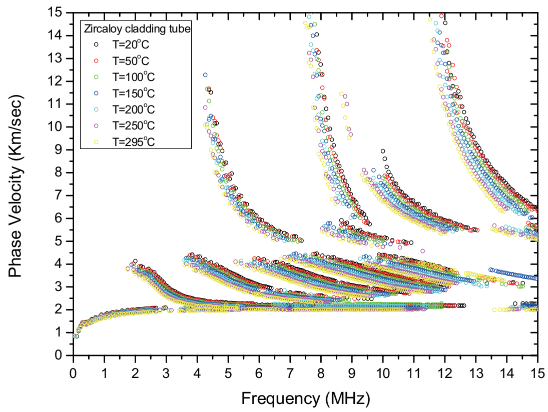

Fig. 4 Measured guided wave dispersions for the Zircaloy cladding tube with different environment temperature

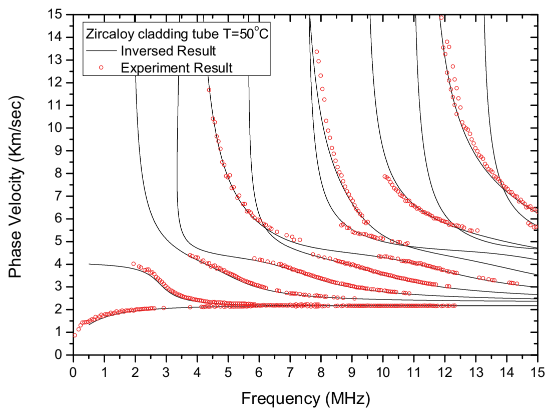

Fig. 5 Measured and inversed dispersions of Zircaloy cladding tube at 50°C

Inversion results of elastic modulus for the Zircaloy cladding tube with different environment temperature are shown in **Fig. 6**, it is found out that the elastic modulus decreases as the temperature increases. According to the inversion results, elastic modulus decreases as the temperature increases and showed a linear relationship.

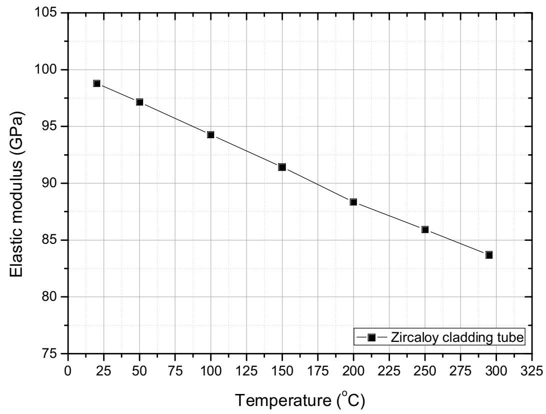

Fig. 6 Inversed elastic modulus of the Zircaloy cladding tube with different environment temperature

5. Conclusions

It is shown that the procedure introduced in the current research is able to relate the phase velocities with temperature. 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 method is potentially useful to to characterizing material property in high temperature environment in a remote and nondestructive way.

Acknowledgment

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References

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