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Characterization of Hydride Orientation in Zircaloy Cladding Tubes with a Laser Ultrasound Technique

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Abstract

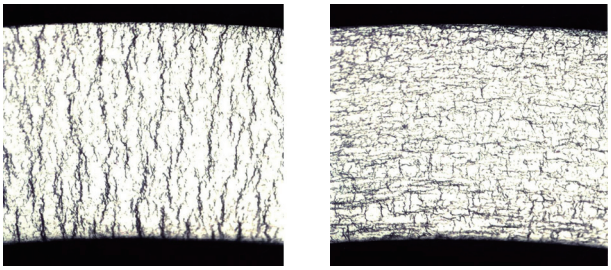
This research is focused on characterizing the ratio of radially(R) orientated hydrides and circumferential(C) ones in Zircaloy cladding tubes with different concentration ratios. A procedure corporate with an experimental technique and an inversion algorism is used to investigate the effects of R/C ratio on the dispersion spectra of guided waves propagating in the tubes. An experimental technique employing laser ultrasound technique is used to measure the dispersion spectra of circumferentially guided waves propagating along the circumferential direction of the cladding tubes. An inversion algorism based on simplex method is used to extract interested properties from the measured dispersion spectra. It is shown that the procedure introduced in the current research is able to relate the phase velocities with different hydrogen concentration. In the meanwhile, this procedure is also able to distinguish the R/C ratio in a quantitative wayl. It is also found out that the bulk elastic modulus increases as the R/C ratio increases.

Key words: Laser ultrasound, dispersion, guided waves, hydride, Zircaloy.

1. Introduction

The degradation of mechanical properties in Zircaloy cladding tubes are directly related to the precipitated hydrides which also cause the hydrogen embrittlement phenomenon. The relation between concentration of the precipitated hydride and hydrogen embrittlement is well known. Recently it is further found out that direction of the precipitated hydride is another key factor influencing the degradation mechanism; hydrides orientated in the radial direction, as shown in **Fig. 1(a)**, can reduce the fracture toughness much more than hydrides orientated in the circumferential direction, as shown in **Fig. 1(b)**.

Guided waves (GW) propagating in tubes have been extensively used to characterize properties of tubes. Axially propagating guided waves (AGW) has been reported to characterize hydrogen concentration in Zircaloys [1]. In this study, circumferential guided waves (CGW) are used characterizing cladding tubes with different concentration ratios between hydrides orientated in the circumferential (C) and radial (R) directions. A inversion technique based on combining theoretical and experimental study is proposed and illustrated in the following sections.



(a) radial (b) circumferential

Fig. 1 Hydrides orientated direction

2. Laser Ultrasound measurements

Dispersion relations of CGW propagating in Zr-4 tubes with 200ppm and 300ppm hydrogen concentration between hydrides orientated in the circumferential and radial directions 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 circumferential direction in the tube by rotation motor combine with mirror set, as shown in **Fig. 2**.

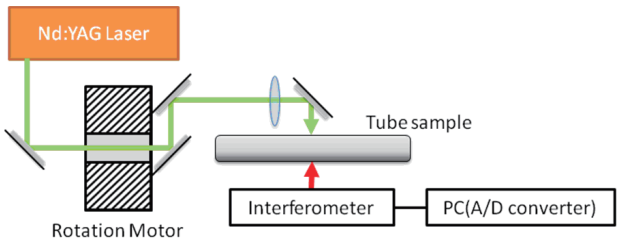


Fig. 2 Experimental configuration of the LUT

3. Inversion with simplex algorism

Following the measurements on the dispersion spectra of circumferentially 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

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inversion method in this study is based on simplex algorism.

4. Results and Discussions

Dispersion curves of CGW measured with the LUT are shown in **Fig. 3** for the Zr-4 sample with different hydrogen concentration. The raising of hydrogen concentration influences the CGW dispersion up-offset at higher modes. Measured dispersions are compared with the inversed results in **Fig. 4**, it is shown that the inversed agree with the measurement very well.

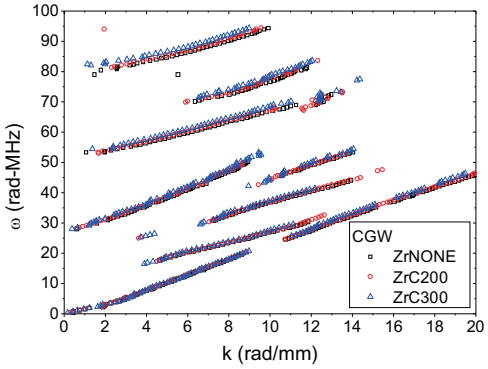

Fig. 3 Measured CGW dispersions for the Zr-4 samples with different hydrogen concentration

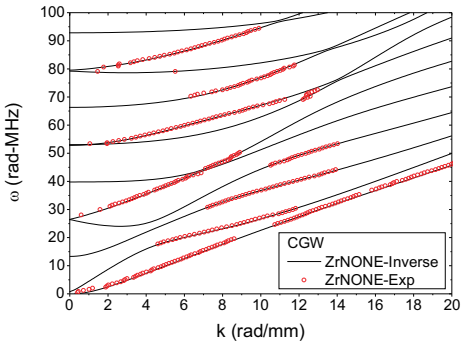

Fig. 4 Measured and inversed dispersions of CGW

Inversion results of elastic modulus for the Zr-4 sample with different hydrogen concentration are shown in **Fig. 5**, it is found out that the elastic modulus increases as the hydrogen concentration increases. Similarly, the different R/C ratios of the inversed elastic modulus results are shown in **Fig. 6.** High R/C ratio means hydrides orientated in the radial direction mostly. According to the inversion results, elastic modulus increases as the R/C ratio increases and showed a linear relationship at the same hydrogen concentration.

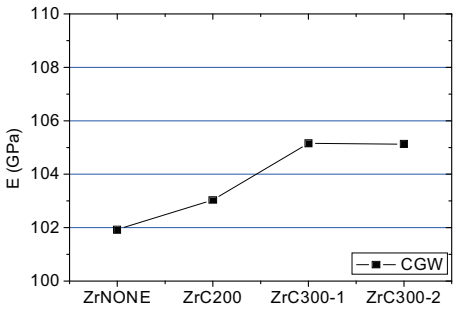

Fig. 5 Inversed elastic modulus of the Zr-4 sample with different hydrogen concentration

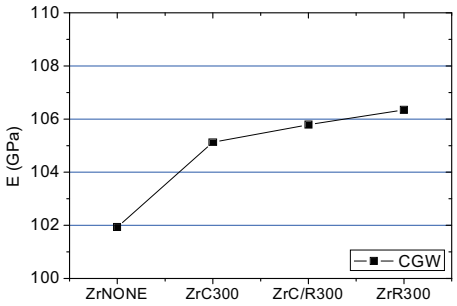

Fig. 6 Inversed elastic modulus of the Zr-4 sample with different R/C ratio

5. Conclusions

It is shown that the procedure introduced in the current research is able to relate the phase velocities with hydrogen concentration. In the meanwhile, this procedure is able to distinguish the R/C ratio in a quantitative way. It is also found out that the bulk elastic modulus increases as the R/C ratio increases. This method is potentially useful to probe the hydrogen concentration and the associated R/C value in a remote and nondestructive way.

Acknowledgment

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References

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