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Characterizing hydride rims on Zircaloy tubes with laser ultrasound technique

I-Hung Liu and Che-Hua Yang (National Taipei University of Technology)

Abstract

A procedure employing a laser ultrasound technique (LUT) and an inversion calculation algorism are reported for nondestructive characterization of hydride rims (HR) in Zircaloy cladding tubes. With the LUT, ultrasonic waves propagating in the Zircaloy tubes with different HR thickness are generated and detected remotely by optical means. By measuring the dispersive ultrasonic wavespeeds with the LUT, together with an inversion technique, relations between the dispersion relations and thickness of HR are established. Good accuracy in measuring the HR thickness is demonstrated. Having the advantages of remote, non-contact and point-wise generation/detection, the LUT serves as a competitive candidate for the characterization of Zircaloy tubes generally operated in irradiative and temperature-elevated environments.

1. Introduction

Zircaloy tube is the material often be used in nuclear power plants for fuel cladding. During the operation time, it will produce “hydrogen embrittlement” and precipitate a hydride layer formed by ZrH_2 on outer or inner surface of tubes in Zircaloy tubes, it is the important reason why the ductility of Zircaloy tube be reduced.

In this research, LUT is the measurement system to get experimental dispersion curves, and simplex method is the inversion algorism to calculate material and geometry properties. Confirmed this research succeeds in developing a set of new non-destructive technique, in the qualitative and quantitative amount of hydride rims are examined, there can be very good results.

2. Experiments and inversion calculations

The LUT system divided into two mean parts, a ultrasound generation and interferometer detection. A ultrasound generation is a pulsed laser, the wave length is 532μm and the duration time is 6.6ns with the 180mJ energy. Detection system monitor the ultrasound propagation with non-contact and remote method on specimens set up by an optical heterodyne interferometer. In order to get the dispersion relation between the frequency and phase velocity, using motion mechanism with generation laser scanning along the axial direction, such as **Fig.1**.

Because of the dispersion curve conceal the only and important information on unique material, it is most important to figure out these information. Such as **Fig.2**, simplex method cooperates with the theory guided wave models of one and two-layered tube is used to be the inversion algorism to calculate the exactly material and geometry properties.

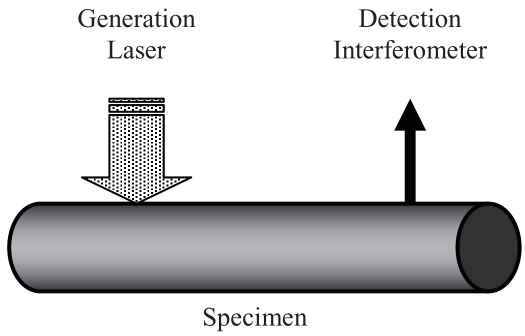

Fig. 1 Experimental configuration

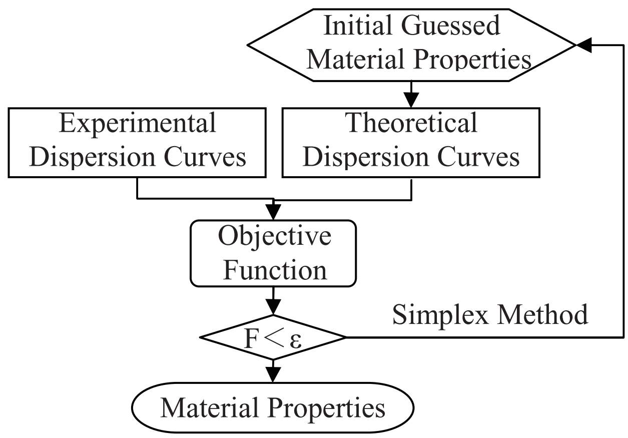

Fig. 2 Inversion algorism configuration

3. Material specimen

Single and double layered Zircaloy tubes are investigated. Two-layered tubes are made up by the Zircaloy matrix and coating the ZrH_2 on the surface either in the inner or outer side of the tubes, as shown in **Fig.3**.

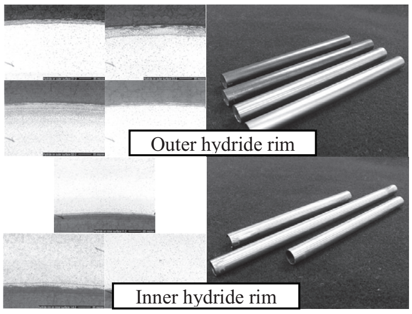

Fig. 3 Zircaloy tube with inner or outer HRs

4. Results and discussions

For reducing unnecessary conditions, make sure of the matrix material properties is the first step to characterize the hydride rim on Zircaloy tubes. **Fig.4** is the experimental results on one-layered Zircaloy tube measured with LUT. In this figure, it proves the LUT can be succeeded in applying to the measurement of dispersion relation, and with very good signal/noise ratio.

Using the inversion algorism introduced before to calculate the material and geometry properties from **Fig.4**, and inverse results is showed in **Table I**. Good accurate inversed results show in this table and the error range of material and geometry properties are all smaller than 2 percentage.

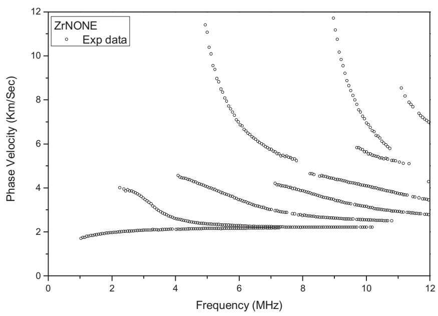

Fig. 4 Experimental dispersion curve on single-layered Zircaloy tube.

Table I. Inverse results for the single-layered tube

	E(MPa)	ν	IR(mm)	OR(mm)
Ave	98717	0.31	4.231	4.792
Error(%)	0.02	0.29	1.57	1.39

With the same LUT system, measuring the dispersion curve on two-layered tubes coated inner or outer hydride rims, such as **Fig.5.**

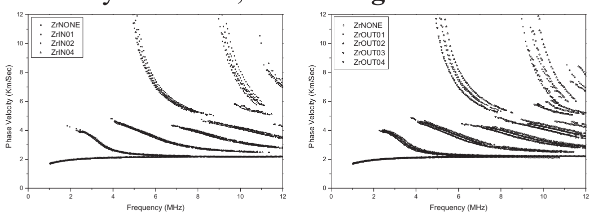

Fig. 5 Experimental dispersion curve on Zircaloy tubes with inner and outer HR.

Before inversion calculation, inversed constant should be determined. The material constants which are calculated from one-layered tube are determined fixed constant, and others constant, such as E, ν, ρ, and geometry parameters of hydride rims, are set as variable parameters to be inversed. The inverse results are divided into two tables, such as **Table II.** and **Table III. Table II.** shows the material properties and **Table III.** shows the geometry constants. Although the error range in two-layered tube is larger than in one-layered tube, only differ by several μm in fact, so this algorism is still with very accurate inverse results.

Table II. Inversed results on material properties of HR.

	Hydride rim		
	E(MPa)	ν	ρ(g/cm^3)
OUT-1	103876	0.30	6.14×10^{-9}
OUT-2	129137	0.31	6.04×10^{-9}
OUT-3	71647	0.29	5.73×10^{-9}
OUT-4	113680	0.32	6.15×10^{-9}
IN-1	92775	0.30	5.99×10^{-9}
IN-2	141489	0.34	5.92×10^{-9}
IN-4	149710	0.32	6.00×10^{-9}

Table III. Inversed results on thickness of HR.

	Hydride rims		
	Inversed(μm)	Actual(μm)	Error(%)
OUT-1	32.7	32.6	0.4
OUT-2	34.5	34.9	1.0
OUT-3	81.5	83.5	2.4
OUT-4	21.2	20.2	5.1
IN-1	12.1	12.5	3.5
IN-2	12.9	13.5	4.2
IN-4	26.9	28.8	6.6

5. Conclusions

This paper demonstrates a procedure employing a laser ultrasound technique and an inversion procedure for nondestructive characterization of hydride rim thickness in Zircaloy cladding tubes. Good accuracy in obtaining the hydride thickness remotely is demonstrated with the current procedure. Results of the current research will serve as useful tool for nondestructive characterization of hydride rims in Zr tubes.

Acknowledgment

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