Characterizing hydride rims on Zircaloy tubes with laser ultrasound technique

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Abstract

A procedure employing a laser ultrasound technique (LUT) and an inversion calculation algorithm 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 wave speeds 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 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\textsubscript{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 algorithm 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 532\textmu m 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 algorithm to calculate the exactly material and geometry properties.

![Fig. 1 Experimental configuration](image1)

![Fig. 2 Inversion algorithm configuration](image2)

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\textsubscript{2} on the surface either in the inner or outer side of the tubes, as shown in Fig.3.
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 algorithm introduced before to calculate the material and geometry properties from Fig. 4, and inverse results is showed in Table I. Good accurate inverted results show in this table and the error range of material and geometry properties are all smaller than 2 percentage.

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 algorithm is still with very accurate inverse results.

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.

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References