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Fuel plate cladding thickness estimation thanks to acoustic microscopy

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ABSTRACT

When the nuclear fuel is in the form of plates, the resulting structures can be seen as heterogeneous tri-layers made of a fissionable core and an aluminum cladding. For safety reasons, the cladding thickness of these plates must be guaranty, and thus measured. Currently, this measurement is done by a destructive method. The purpose of this project is to replace this procedure by a non-destructive measurement thanks to acoustic microscopy.

The presentation will focus on the specifications of the acoustic microscope to allow interaction between the ultrasonic waves and the granular interface. The signal processing allowing the time-of-flight estimation will then be presented. Finally, a comparison between the current process results and the thickness estimations obtained through acoustic microscopy will be made, proving the relevance of a non-destructive control of the fuel plates to image the cladding thickness.

1 Introduction

When the nuclear fuel is in the form of plates, the resulting structures can be seen as heterogeneous tri-layers structures made of a fissionable core and an aluminum cladding [1] [2] [3]. At the end of the manufacturing process, several quality controls are performed. One of these quality controls is the measurement of the cladding thickness, where, thickness between the plate surface and the uranium is measured. This thickness must not be lower than a certain threshold, typically 200 µm.

Currently, this measurement is done by a destructive optical method. A series of plates is produced, and some of them are cut and destroyed for the optical measurement. If these controlled plates are in conformity, the series is considered as well, otherwise the series is considered as defective. The purpose of this research project is to investigate the possibility to replace the destructive measurement by a non-destructive measurement thanks to the acoustic microscopy. This replacement will allow us to preserve the controlled plates.

The measurement of cladding thickness by acoustic microscopy requires the study of the interaction of ultrasound with a granular interface. This interface is highly heterogeneous where the grains have various shapes with dimensions, also variable from ten microns to hundred microns. The desired resolution requires the implementation of a specific microscope by adapting the mechanics, electronics, and the various transducers. The measurement of the time of flight requires the implementation of an adapted and specific signal processing for these thickness measurements. An acoustic microscope adapted to this application was designed, procured, installed and tested in collaboration with a supplier and new signal processing methods were implemented.

In order to validate the new non-destructive method, plates were analyzed acoustically and then optically after their destruction. The results of the acoustic and optical cladding thicknesses have been compared.

This research work is in collaboration with IES (Institut d'Electronique et des Systèmes) of Montpellier and Framatome Romans-sur-Isère [4] and has received funding from the EURATOM research and training program 2014-2018 under grant agreement LEU FOREVER n°754378. The optical destructive measurements were performed by "Unité de Catalyse et Chimie du Solide" from Lille University in France [5].

2 Preparation of the plates

In order to be able to compare optical and acoustical measurements, a specific marking procedure has been developed after a bibliographical study [6]. In particular, the current optical control consists in performing optical measurements on points of a measurement line, identified after plate cutting. The operator then visually identifies the areas with minimal cladding thickness. The objective of the marking procedure is then to allow a clear identification of this measurement line. For industrial reasons, the punching is standardized and is carried out on a surface of 28 mm x 10 mm. These punched pieces are called coupons, see Fig.1(a).

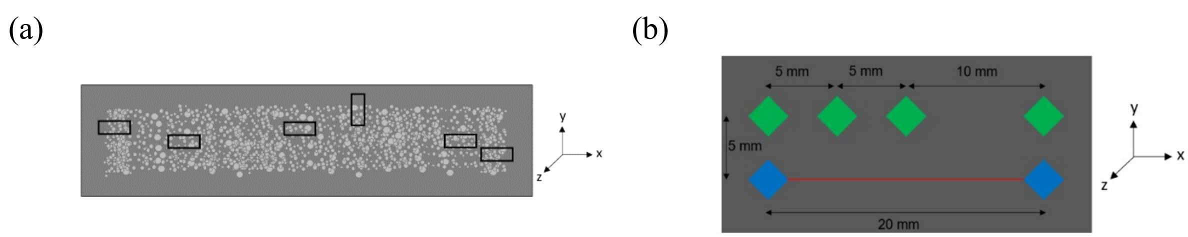

Fig.1 (a) Coupon to be analyzed in a plate; (b) Position of the indentations for each coupon.

A marking method was designed to reduce the relative positioning error of both methods. It was carried out thanks to a durometer of the PRESI brand. For each plate, the number of coupons was determined according to the size of the plate. Indentations were made on each coupon before the acoustic measurement. Each coupon has six indentations. The two blue indentations in Fig.1(b) designate the cutting line in red and the four green indentations allow us to differentiate the right from the left after cutting hence their asymmetry and to locate the measurement line if the two blue indentations are overtaken during polishing.

3 Acoustic microscopy

A specific acoustic microscope has been developed by the IES, UMR CNRS University of Montpellier, to non-destructively measure the cladding thickness along the defined measurement line [7] (see Fig. 2(a)). It allows the control of the motors along the X, Y and Z axes and a choice of parameters. The control software allows to define the resolution, the sampling frequency, the scanning mode, the scanning speed, etc.

(a) (b)

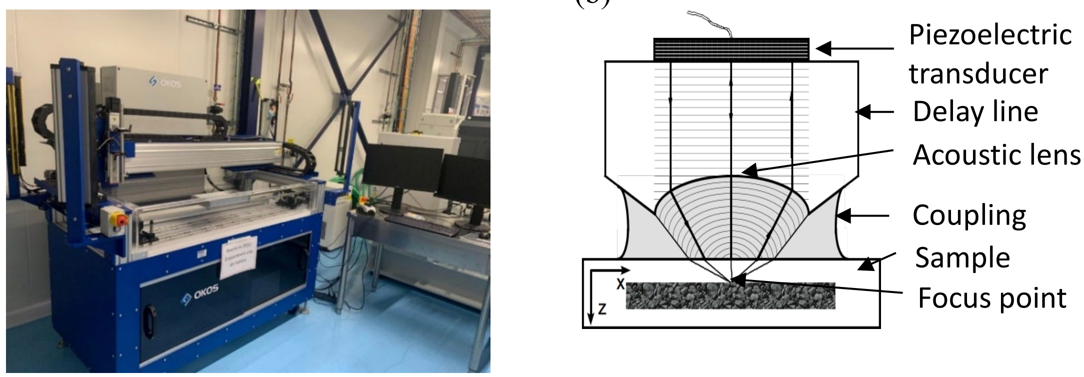

Fig.2 (a) OKOS acoustic microscope; (b) Functioning principle of a focused transducer.

Specific transducers were designed to allow an ultrasonic focus onto the cladding/fuel interface, Fig.2(b). The first one, with a 150 MHz central frequency allows the identification of large thicknesses, while a 200 MHz high frequency transducer has been designed for smaller thicknesses. They were both conceived to allow echo-separation between signals coming from the surface of the plates and those reflected by the interface (see Fig.3(a) and (b)).

(a) (b)

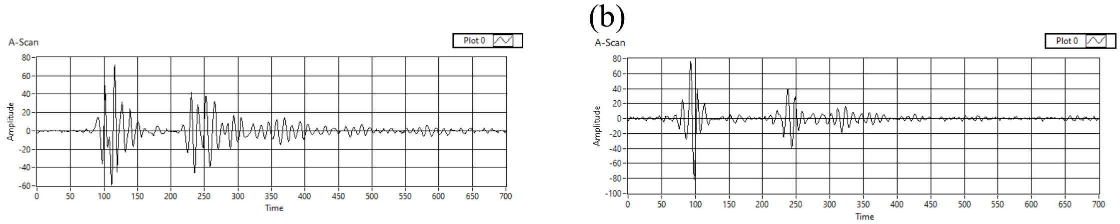

Fig.2 Zoom of an A-Scan with (a) the 150 MHz frequency transducer; (b) the 200 MHz frequency transducer.

For control feasibility, the plates are placed horizontally in a specifically designed sample holder allowing us to adjust the flatness for each plate, ensuring no deflection or banana effect on the plates (see Fig.3(a)).

(a) (b)

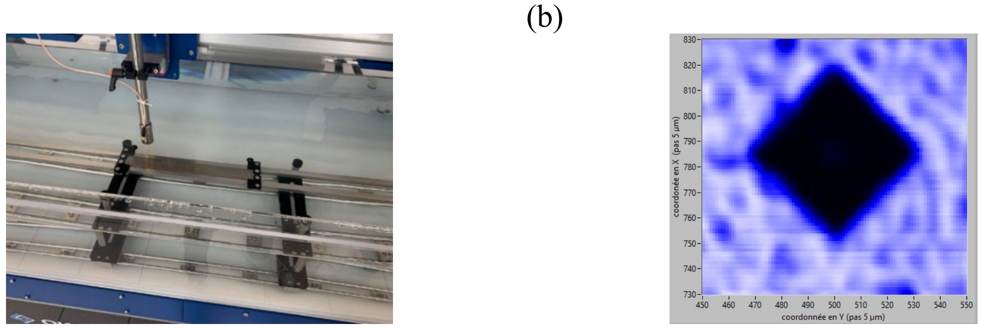

Fig.3 (a) Plates in the sample holder; (b) Ultrasonic image of one of the plate mark.

For each coupon, a surface acquisition is first made to locate the indentations, Fig.3(b). The surface images are acquired by focusing the acoustic beam on the surface of each plate. A display device under LabVIEW has been developed in parallel with the control software. It allows, from the acquired data in *.bin format, to reprocess the signals to display images of surfaces or thicknesses of the cladding. This latter is determined through the identification of the difference in time of flight between the acoustic signals corresponding to the reflection onto the surface of the plate and the fuel grains. 2D ultrasonic images of an area including the measurement line were then performed (Fig.4(a)). They will be used, after plate cutting, to reconstruct the optical measurement line.

(a) (b)

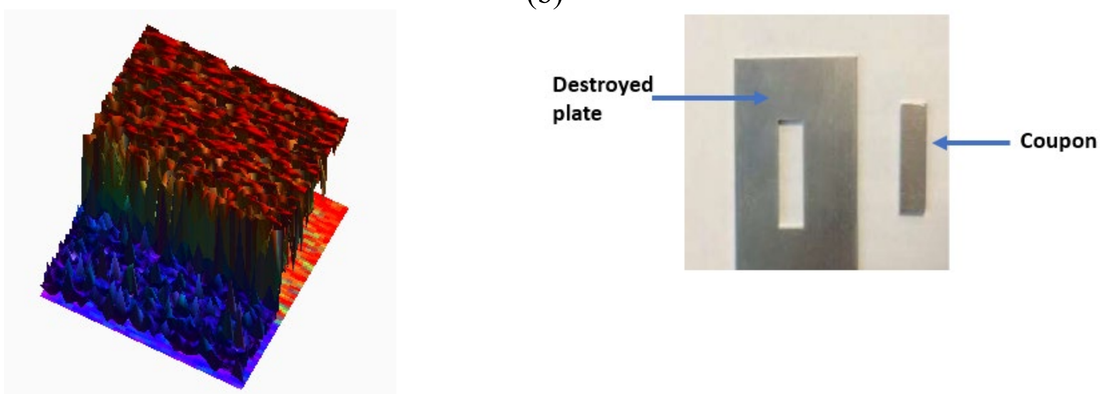

Fig.4 (a) 2D ultrasonic image of the interface; (b) Coupon extraction from the plate.

4 Plate punching and optical measurement

After the acoustic imaging process, optical measurements were made to evaluate the performance of the non-destructive method. The first operation to realize to be able to perform optical measurements is the punching [8]. The plates had to be transported from the IES laboratory in Montpellier to the Framatome site in Romans-sur-Isère for this operation. The cutting was done by manual punching. A cutting guide is placed on the plate in the area of the piece to be punched. Coupons are then obtained and the destroyed plate is discarded (Fig.4(b)).

The second step of the optical measurement is the polishing. For practical and availability reasons, this operation had to be performed at the Chevreul Institute of University of Lille [5]. A transport from Romans-sur-Isère to Lille of the coupons was made. The polishing is done in order to obtain an optically exploitable surface, and thus to be able to carry out the measurement of thickness using the optical microscope. Polishing is done manually and individually (coupon by coupon) with a semi-automatic polisher of the brand Struers Tegramin – 30. Optical measurements are then performed using a Keyence VHW optical microscope [9].

The first step of the optical measurement is to identify the position of the end of the polishing and therefore the position of the optical measuring line that will be compared to the ultrasonic measurements.

Since both stamping and polishing are manual steps, this results in offsets of a few microns between the ideal position and the effective one. The maximum offset during punching and polishing is estimated to be 112 µm. Offsets are quantified for each of the coupons so that the optical measurement line can be extracted from the ultrasonic 2D measurements. The distance between the cutting line and the two indentations A and B is so measured (Fig.5(a)).

For the cladding thickness measurement, an optical image of the coupon profile is made. From this image, the distance between the surface and the grains is measured along a 20 mm measuring line with a 50 µm step. These measurements are made manually with the help of the Keyence optical microscope processing software.

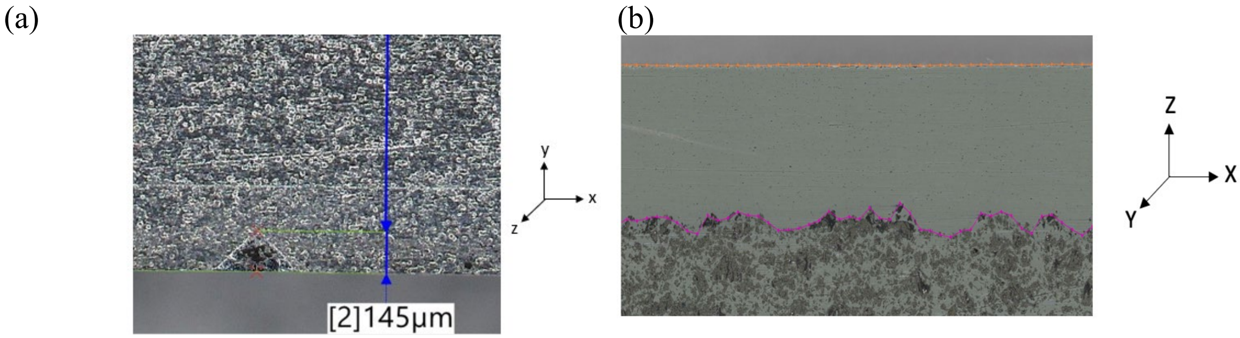

Fig.5 (a) Optical identification of the measuring line; (b) Optical thickness measurement on an optical image part.

Fig.5(b) presents an optical image where the fuel is seen, at the bottom, encapsulated in the form of grains. The thickness of the cladding consists in measuring the thickness between the surface (in orange) and the first uranium grain detected. The reconstructed 50 µm interface is represented in pink in Fig.5(b). For all measurements, the length of the optical line has been fixed to 2 cm.

5 Cladding thickness identification through optical and ultrasonic means

After the non-destructive acoustic acquisitions, the destructive optical measurements, and the signal processing for the acoustic measurements, the different results are compared. For each plate, several coupons were studied acoustically and punched for optical measurements. For industrial, financial and temporal reasons, all the coupons could not be studied optically. In the following, only one set of results will be presented and analyzed.

The optical measurements are made with a 50 µm step. To allow a high-quality identification of the measurement line, the acoustic acquisitions were made with a 5 µm step. After the spatial repositioning on the measurement line, an average of 10 is applied. Fig.6. below presents a comparison between the optical (blue) and acoustic (red) measurements of a coupon of a measurement line.

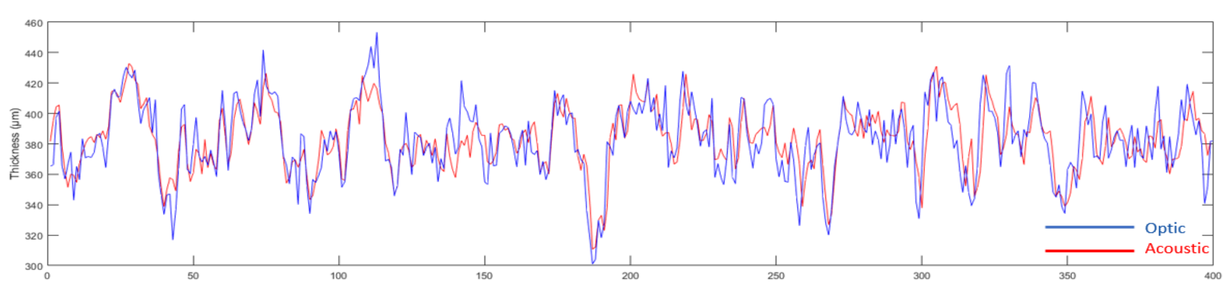

Fig.6 Optical and acoustic thickness measurement of the measuring line.

For this acoustic configuration, the average of the absolute differences between the thicknesses of the two curves, optical and acoustic ones, is 12 µm.

The histogram in Fig.7 allows us to analyze the distribution of acoustic and optical differences.

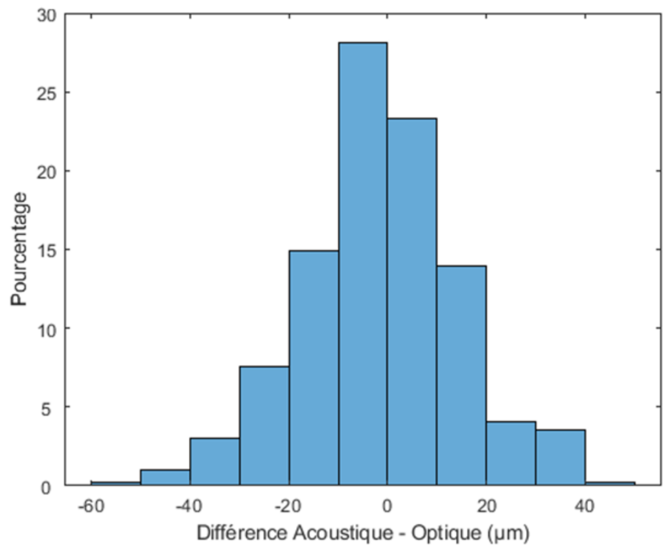

Fig.7 Histogram of the distribution of acoustic and optical differences.

Plate	Plate 1		Plate 2		Plate 3	Plate 4	
Coupon	A	B	A	B	A	A	B
Difference	11 µm	15 µm	12 µm	16 µm	17 µm	14 µm	15 µm

Table1. Differences between the acoustic and optical measurements of a set of coupons.

These types of comparisons were made for a set of coupons and table 1 presents the average of the absolute differences between the acoustic and optical measurements of the different coupons studied from 4 different types of plates. This clearly indicates the reliability of the acoustic imaging method to non-destructively reconstruct the cladding/fuel interface and then infer the cladding thickness.

6 Conclusion

In this study, we have determined the choice of an acoustic microscope adapted for the measurement of the thickness of the fuel plates cladding. We have determined the electronics, the mechanics, the transducers and the signal processing adapted to the equipment and the objects to measure.

The fuel plates were first marked at Framatome in order to be repositioned. The marking method has been designed to allow for the identification of the measurement lines and to reduce the relative positioning error of the two methods. The relative positioning error is the main source of comparison inaccuracy.

The non-destructive acquisitions by acoustic microscopy have been done at the IES laboratory, then the destructive optical control has been done between the Framatome site for the first step, and the laboratory of the Chevreul Institute of the University of Lille for the last steps.

The thickness measurement with the acoustic method was done with two frequencies. The frequency of 150 MHz was intended for large thicknesses, and the frequency of 200 MHz was intended for small thicknesses.

We were able to compare acoustic measurements of fuel plate thicknesses with the optical reference measurements. The average absolute differences between the two types of measurements are less than 20 µm. Such a result is very promising and validate the industrial interest for such a technic. The device is in place in the Framatome R&D workspace. It is an industrial demonstrator. Now the process will be qualified on numerous plates, conform and not conform ones, in order to determine the interest to go further.

7 Acknowledgement

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8 References

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