NONDESTRUCTIVE EVALUATION OF PLATE TYPE NUCLEAR FUEL ELEMENTS DURING MANUFACTURING STAGE USING ULTRASONIC TEST METHOD

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ABSTRACT

Structural discontinuities, such as cracks and bonding lacks at the core/cladding interface can be introduced in plate type nuclear fuel elements during the manufacturing stages, due to the mechanical and thermal processing conditions. They can reduce the performance of the nuclear fuel during its operational life or contribute to its premature failure. Plate type nuclear fuels (PTNF) consist of a core formed by a dispersion of UO$_2$ into a metallic matrix, involved by a metallic cladding. Nondestructive testing methods such as eddy current, radiography and ultrasonic have been used to detect and monitoring discontinuities generated in the fuel’s manufacturing stage, each one presenting advantages and limitations. The use of ultrasonic testing for this purpose presents two main difficulties: the small thickness of the plates as well as the presence of materials with different characteristics. The study described in this paper presents the methodology used in the evaluation of a prototype of PTNF by ultrasonic testing method, using different test techniques and transducers. The main results obtained and the next steps to be developed in this activity are discussed.

1. INTRODUCTION

Plate type nuclear fuels consist of a core formed by a dispersion of UO$_2$ into a metallic matrix, involved by a metallic cladding. The experiments described in this paper were performed in samples of plate type nuclear fuels developed at the CDTN nuclear fuel laboratory facilities. Their core consists of a dispersion of UO$_2$ in a stainless steel matrix and the material used as cladding is the stainless steel. However, the procedures presented can be adapted to be used in different sets of core/cladding materials.

One of the most important stages in the plate type nuclear fuels manufacturing is the development of nondestructive methods and techniques to detect and sizing discontinuities induced during the manufacturing process. These discontinuities are induced mainly due to the process variables, such as rolling temperature, severity of the section reduction during the rolling operations and the characteristics of the materials involved. Nondestructive test methods such as visual tests, radiography, eddy current and ultrasound scan are used for this purpose. Their use allows the detection of different discontinuities such as cracks (eddy current testing) and failures at the core/clad interface [1] (ultrasonic testing), as well as to perform thickness measurements in the plate type nuclear fuel. However, the reliability of the information obtained depends on the test methodology used.
The use of ultrasonic testing method for bonding failures detection at the clad/core interface presents two main difficulties: the small thickness of the fuel plates and the presence of materials with different characteristics in the core. These restrictions can be overcome with the use of special ultrasonic transducers as well as reference standards specially designed to allow the establishment of the test system sensitivity. So, the experiments were performed using two different types of ultrasonic transducers: contact ultrasonic delay line transducers with frequencies of 10 MHz and 15 MHz and immersion transducers of different characteristics (normal, line focused and spot focused) and frequencies (4 MHz and 10 MHz) [2]. Besides, artificial discontinuities were machined in a plate type nuclear fuel sample, using an EDM machine, in order to produce reference reflectors located in specific regions of the plate.

2. EXPERIMENTAL METHODOLOGY

2.1. Equipment and Accessories

2.1.1. Ultrasonic test equipment and transducers

Experiments were performed using Epoch II ultrasonic testing equipment and the following ultrasonic transducers:

a) DTZ 57AB920 delay line transducer – 10 MHz
b) DTZ 57AB985 delay line transducer – 15 MHz
c) 1421 Karl Deutsh immersion transducer – 4 MHz - œ 15 mm
d) 1450 Karl Deutsh immersion transducer – 4 MHz - œ 7 mm
e) 1514 Karl Deutsh immersion transducer – 4 MHz - œ 15 mm – focused (line)
f) L10ML15 Krautkramer immersion transducer – 10 MHz - œ 8 mm – focused (line)
g) SIJ Automation immersion transducer – 10 MHz - œ 9 mm – focused (spot)
h) DIZ 57A8919 Automation immersion transducer – 10 MHz - œ 8 mm – focused (spot)

The ultrasonic equipment and transducers used can be observed in Fig. 1.

Figure 1. Ultrasonic test equipment (a); delay line transducers (b); immersion transducers (c).
2.1.2. Device for beam profile plots

This device was used to obtain the ultrasonic beam profiles of the immersion transducers used in the experiments. It consists of a small Plexiglas tank containing, in its center, a small steel ball that acts as a sound wave reflector. This tank is fixed in an X-Y table that allows its motion in two orthogonal directions. The transducers are assembled in a mechanism, also fixed in the X-Y table that allows its motion in the Z direction, perpendicular to the X-Y plane. The complete set used can be observed in Fig. 2. The sound beam profile plot of the immersion transducers is necessary to select the distance between the transducer and the plate surface, in order to locate the focal point of the transducer at the region of the plate under investigation.

![Device for beam profile plot](image_url)

**Figure 2. Device for beam profile plot.**

2.2. Reference Standard

The reference standard used to establish the more adequate test conditions for plate type nuclear fuels was obtained from a plate of small dimensions, manufactured in the same conditions as the used for the plates developed at the CDTN nuclear fuel laboratory facilities.

Artificial discontinuities, such as flat bottom holes [3] with different diameters and slits with different length and width, were machined at the plate surface, identified as A surface. The depth of each discontinuity was chosen in order to verify the response of the test system, using transducers with different characteristics, to detect small discontinuities at different depths, mainly those corresponding to the core/cladding region.
The final configuration of the reference standard manufactured can be seen in Fig. 3 and Fig. 4. In this reference standard, the core of UO$_2$/inox was located in a small part of the central region of the plate.

![Figure 3. Position of the artificial discontinuities and the core region at the A surface of the reference standard.](image)

![Figure 4. View of the longitudinal section of the reference standard, indicating the positions and depths of the artificial discontinuities.](image)

### 2.3. Measurements

Measurements were carried out with the ultrasonic transducers located at A surface of the reference standard. The measurements performed using the delay line transducers were made using the contact technique. Those performed using the immersion technique were carried out using an X-Y device, installed in a tank used for immersion ultrasonic inspection.

The test configuration set can be observed in Fig. 5.
2.4. Results

Typical results obtained from scanning performed at the A surface of the plate, using the contact technique, are shown in Fig. 6. In Fig. 6(a) the signals are referent to a region of the plate out of the core region. In this region, in the path of the ultrasonic beam, are just the frame and the two plates used as cladding. In Fig. 6(b) the signals are referent to a region of the plate just above the core. In this region, in the path of the ultrasonic beam, are core and the two plates used as cladding. It can be observed that the dimensions presented by the ultrasonic test system in this region are slightly bigger than those obtained in the region out of the core region, in spite of the fact that they have the same external dimensions. This effect is due to the fact that the sound propagation speed in uranium is smaller than it is in steel. In both situations there is no failure in the frame/cladding or core/cladding bonding.
Typical signals of failure in the core/cladding bonding, obtained at the core region, are shown in Fig. 7. The ultrasonic beam is reflected at a core/cladding interface.

Figure 7. Typical ultrasonic signals of failure in the core/cladding bonding.

During the scanning of the plate from the A surface, the flat bottom hole with 2.00 mm diameter and 1.90 mm depth was clearly detected by the test system. Otherwise, the smaller flat bottom hole (FBH) that could be detected at the depth of 0.50 mm was the 2.50 mm diameter FBH and, in this case, just by a drop in the back wall echo. The corresponding signals are shown in Fig. 8.
Figure 8. Ultrasonic signals referent to a 2.00 mm diameter flat bottom hole located at 1.90 mm depth from the A surface (a) and back wall drop, revealing the presence of the 2.50 mm diameter flat bottom hole located at 0.50 mm depth from the A surface (b).

The slits were not detected by the test system with the delay line transducers used.

The results obtained from the immersion tests showed that the 4 MHz normal immersion transducers were not able to detect slits, flat bottom holes or failures in the core/cladding bonding. The 4 MHz line focused immersion transducer could detect the 2.00 mm diameter flat bottom holes located at depths of 0.50 mm and 1.90 mm. The 10 MHz line focused immersion transducer could detect just the slits located near to the surface, due to its high subsurface sensitivity and low penetration capability. It could not detect flat bottom holes nor failures in the core/cladding bonding. The 10 MHz spot focused transducers could not detect the discontinuities of the reference standard.

In similar studies performed with fuel plates with different composition, using transducers of 5 MHz, 10 MHz, 15 MHz and 22 MHz, the sensitivity of the test system used allowed the detection of reflectors with size equivalent to a 2.5 mm diameter flat bottom hole, result similar to the presented in this paper [4].

3. CONCLUSIONS

In this initial study for plate type nuclear fuels evaluation using ultrasonic testing, the best results were obtained using high frequency delay line transducers (10 MHz and 15 MHz) and line focused transducers of low frequency (4 MHz). Also, it was established the necessity of the use of transducers with different characteristics, to improve the test results. The next steps in this research work are the development of a mechanical device to perform automated scans of the plate and the development of a software to allow obtaining C-Scan images of the plate associated with the transducers position during the plate surface scans.

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