COMPUTED TOMOGRAPHY AND ULTRASONIC TESTING OF URANIA FUEL PELLETS

P.D.Sutton and L.R.Hillier
General Electric Canada
107 Park Street North
Peterborough,Ontario, K9J 7B5, Canada

B.D. Sawicka
Atomic Energy of Canada Ltd.
Chalk River Nuclear Laboratories
Chalk River, Ontario, K0J 1J0, Canada

INTRODUCTION

Natural uranium dioxide nuclear fuel for irradiation in CANDU reactors is manufactured by General Electric Canada. To ensure the fuel does not rupture,pellet chipping and cracking is controlled. While not apparent in the green compact stage chips and cracks are readily observed after sintering and are generally located at the ends of the pellets

There are several mechanisms by which such cracks are formed. Among these are: powder particle size variation; compaction condition; type of lubricant; and the condition, geometry and type of material from which the die is constructed [1]. In this work, variable compaction conditions were used to induce cracking in green pellets. followed by a study to determine if a non-destructive testing techniqe could be found to detect these conditions in green compacts. Two methods were used; Computed Tomography performed by Atomic Energy of Canada Limited and Ultrasonic Testing performed by GE Canada Inc. Each technique will be dealt with separately in this paper.

PELLET PREPARATION

A high speed mechanical press was used to press the pellets from granulated powder. They were then sintered at high temperatures and centerless ground. Double-ended pressing was simulated by pulling down the die table at the same time that the upper punch was advancing into the cavity. Through this process green compacts exhibit a "press-line" or ring located approximately 8 mm from the top end of the compact (Fig. 1). This line is a plane of constant density and its location along the pellet is an indicator of the relative amount of force applied to the top and bottom of the pellet. The green density of the pellets averaged 5.4 Mg/m^3 or 50% theoretical. After sintering, the average density was approximately 10.80 Mg/m^3 or 98% of theoretical density. All pellets were prepared from the same powder and via the same powder preparation technique; only the pressing force was varied to induce cracking. The same pellets were used for both test techniques.

TESTS

Tests were conducted on 5 pellets, numbered 2, 4, 6, 8, and 10 with the pressing pressure increased from pellet 2 to 10. Top ends of pellet 6 and pellet 10 are the ones of interest in this program for correlation of CT and UT techniques.

ULTRASONIC TECHNIQUE

The pellets were ultrasonically scanned at three stages of manufacture: as a green compact; after high temperature sintering; and after centerless grinding. The pellet was mounted vertically in a rotating chuck. (Fig. 2). The transducer was oriented normal to the surface being scanned. The indexing and pulsing of the transducer, and rotation of the pellet, were computer controlled. The UT image is generated from a series of concentric scan lines. On completion of all scan lines the computer displays a colour image of the test results.

END CRACKING MEASUREMENTS

(1) An axial scan of the cylindrical surface on the z axis for 5 mm at each end of the pellet.
(2) A radial scan of the flat surface on the x axis for 5 mm at each end of the pellet.

Ultrasonic reflections to a depth of 1 mm were monitored and presented in color in 90° segments on the computer screen at the end of each scan. The colours represent the amplitude of the reflected signal in the gate. A scan consists of 100 scan lines at 0.05 mm per line. The scan presents 360 degrees of circumference and 5 mm of axial or radial distance.

The GE ultrasonic "microscope" has demonstrated that with the 50 MHZ, 0.15 mm spot transducer the microscope can reliably detect defects in the order of 0.05 mm.

ULTRASONIC TEST (UT) RESULTS

Information from five pellets was collected and the results from pellets in which defects were identified will be discussed here.

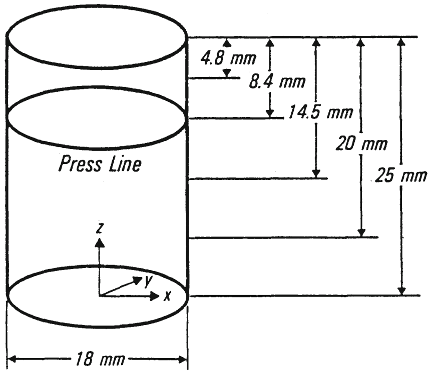

Fig 1. Location of Radial Scans on a Green Compact

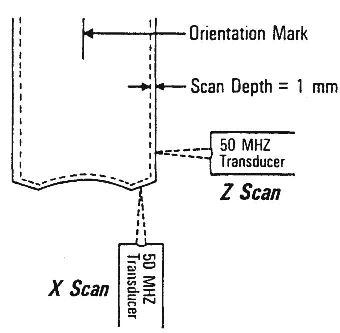

Fig 2.Transducer Orientation

Pellet 4 BOTTOM END RADIAL SCAN

This ultrasonic image of the green compact shows major ultrasonic indications that cover a large area. These indications have distinct shapes.(Fig 3). No visible discontinuities were observed in the green compact.

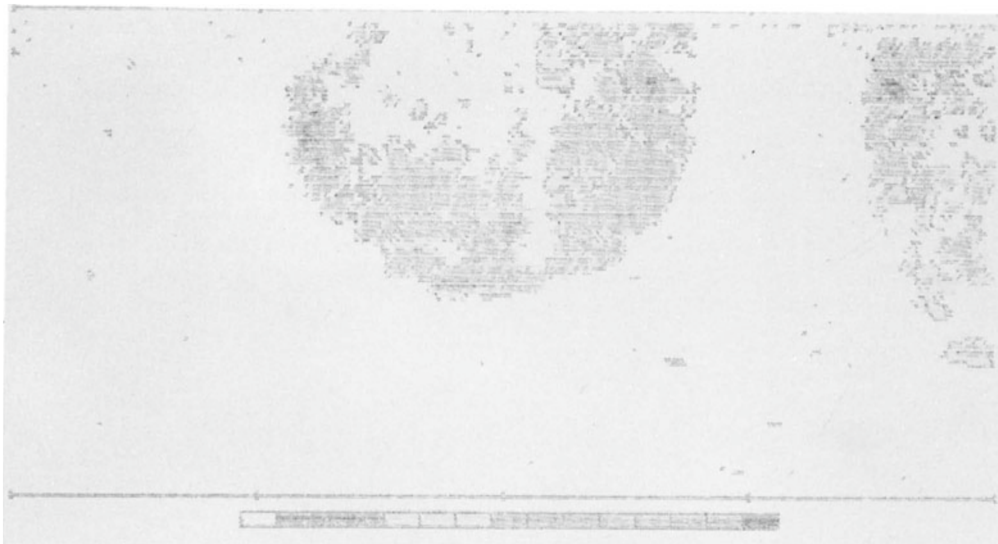

Fig 3. UT Image of Green Compact Shows Major Ultrasonic Indications

Fig 4. UT Image of Sintered Pellets; Shapes are Pronounced but Smaller in Size

The distinct shapes became much more pronounced but smaller in size and closer together after sintering. (Fig 4). A "bubble" effect was visible in this area and after centreless grinding a portion of this "bubble" area chipped off.

Pellet 6 BOTTOM END AXIAL SCAN

Of special interest was a faint circular pattern that encompasses much of the 5 mm scan in the green compact. No visible discontinuities were observed in this area.

After sintering and centerless grinding this faint circular area became much more pronounced and smaller in area. A crack open to the surface was also visible.

Pellet 6 TOP END RADIAL SCAN

The ultrasonic image and visual observation of the green compact showed two distinct areas of chipping in the 1st and 3rd quadrants. Between these two areas and separated from the solid line at the top of each quadrant was a distinct line of high ultrasonic reflections indicating possible end cracking. This area of high ultrasonic reflectivity continues to show up after sintering and final grinding but did not break away from the pellet.

Pellet 10 TOP END RADIAL SCAN

Similar to pellet 6 this ultrasonic image in Fig. 5 of the first scan of the green compact shows the distinct areas of chipping that are visible by eye and also a line of high ultrasonic reflections between these chipped areas. On this particular sample the areas of high ultrasonic reflectivity did break away from the pellet during sintering and final grinding.

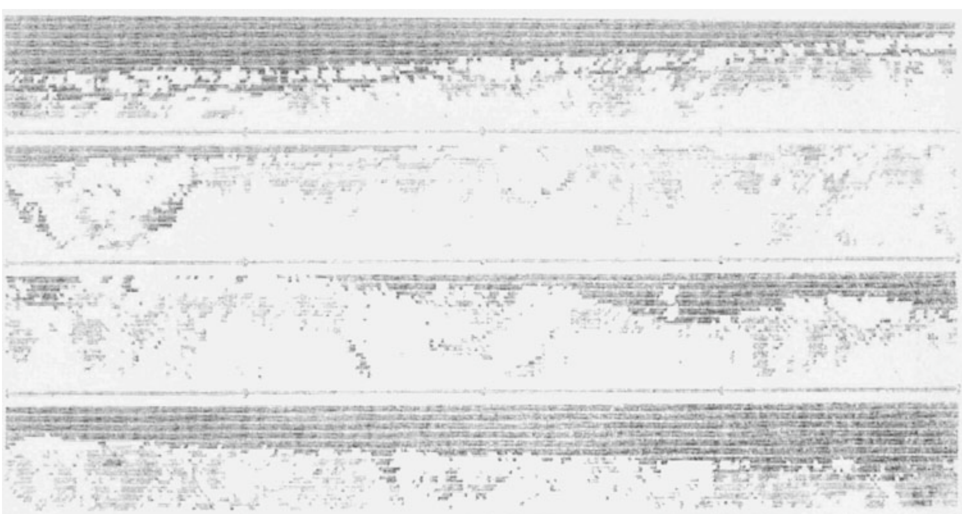

Fig 5. UT Image of Green Compact Shows Distinct Areas of Chipping

COMPUTED TOMOGRAPHY (CT) TECHNIQUES

Computed Tomography permits the recording of two dimensional images in a three dimensional object without distortion and offers high detectability for defects and fluctuations in material distribution. CT technique was applied previously for characterizing ceramics including determination of material distribution in pressed compacts, cracking due to sintering, distribution of various phases in multiphase cermanics, etc.,[2].

The CT images of uranium pellets were measured using the CT scanner built and operated at Atomic Energy of Canada Ltd. An Ir-192 source with average energy of 470 KeV, was the best choice for 2cm of uranium.

Images are constructed mathematically and stored in digital form on a computer disk. They can be displayed on a video screen with different densities represented by different colors.

To measure the density distribution and detect the volumetric defects, several transverse (x-y) scans and longitudinal (x-z) scans were measured on pellets 6 and 10. The end cracks were attempted to be observed in the "top" scans (z=0).

COMPUTED TOMOGRAPHY RESULTS

Density Distribution; Pellet 6

Four Transverse (x-y) scans at Z = 4.8 mm , 8.4, 14.5 and 20 mm were taken (Fig. 1).

Two of the scans with density profiles are presented. The graph scale spans 10% of maximum density.

As seen in Fig. 7 from the scan in the plane of the pressing ring (Z = 8.4 mm) density is practically uniform with a slight decrease at the circumference. In all other cross sections there is a substantial density variation along the radius. (i.e. Fig. 8).

The range of density variations is also shown graphically in Fig.9. Fig. 10 shows the longitudinal (x-z) scan of pellet 6.

This pellet had a crack, observed visually at the surface close to the top end along a large part of the circumference. The CT scan crossed both the crack area and a non-crack area. The crack area is upper left and the non crack area is lower right. The crack is not seen in the CT image but the density was measured higher in the crack area.

Density Distribution; Pellet 10

For pellet 10 several (x-y) scans and several (x-z) scans were conducted. Similar to pellet 6, pellet 10 had a crack along the circumference. Density distribution within this pellet, determined from the CT data of the (x-z) scan, is presented in Fig. 11.

The CT data for pellet 10 indicate that the density distribution within the pellet is generally similar to that for pellet 6, but the density variations are stronger (see for example, Figs. 9 and 11).

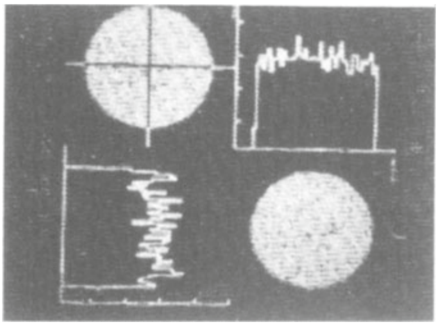

Fig 7. CT Image of Green Compact
Z = 8.4mm; Density is Uniform

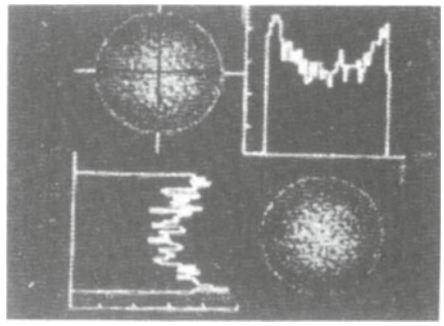

Fig 8. CT Image Showing Density
Variation in Green compact

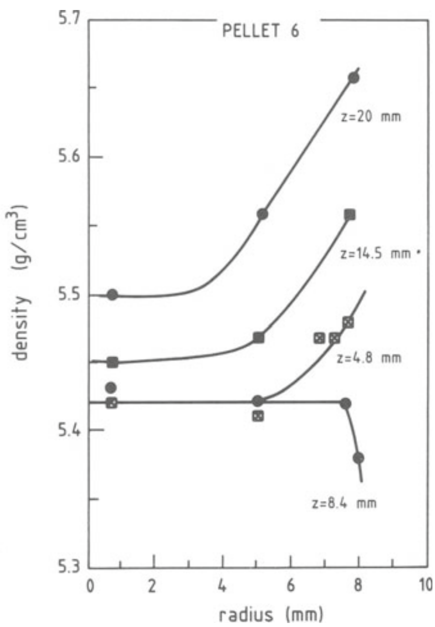

Fig 9. Density Variation for Various Radial Scans

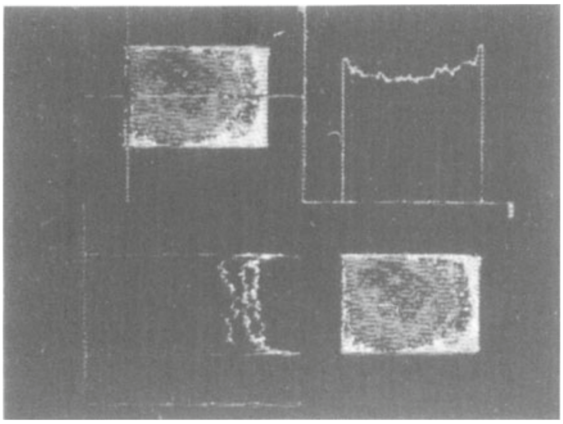

Fig 10. CT Image of Longitudinal Scan of Green Compact

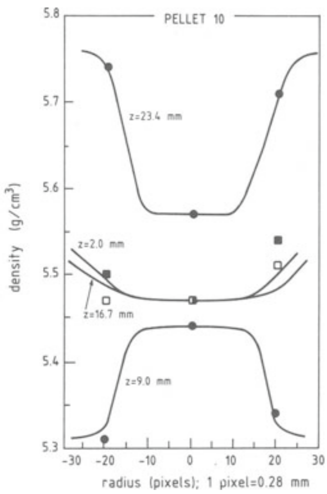

Fig 11. Density Distrubtion for Various Radial Scans

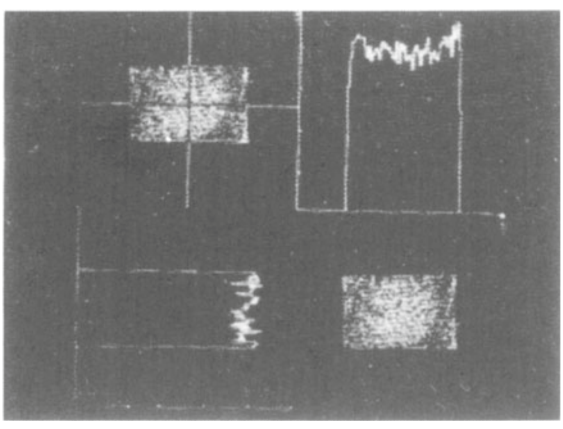

Fig 12. Density Distribution for Sintered Pellet is much more Uniform

Density Distribution; Sintered Pellet

The x-z scan for this pellet (Fig. 12) shows than the density within the measured cross section is much more uniform that for green compacts, nevertheless some small density variations are observed. The density distribution is similar to that for green compacts, but the density changes are much smaller, less than 1.5% along the pellet and still smaller across the pellet. Thus, sintering caused a uniformization of the density distribution as expected. However, the original distribution of the material due to powder compaction was still preserved to some degree.

END CRACKING

End cracking can occur at both ends but more often at the "top" end. Transverse (x-y) scans were made on all pellet top ends (z=0) to see if any cracks can be detected by CT. A strong asymmetry was observed in almost all the images, which could indicate cracks and their location. Unfortunately this asymmetry was found to be caused by a slight deviation of the pellet top plane from the scan plane. Therefore the present results are inconclusive. Various surface features are seen showing the sensitivity of CT images to end crack detection. Therefore we can conclude, that CT images are sensitive enough to detect the end cracks. While the near surface cracks were not resolved in the (x-z) scans, there is a correlation between the occurrence of the cracks and the presence of higher density regions.

CONCLUSIONS

Thus it has been established that ultrasonic evaluation of green compacts can identify areas which will later end crack or chip and these areas are associated with high density gradients.

Data obtained from Computed Tomography and Ultrasonic Testing correlate to yield complementary information: UT provided information on defective regions down to 1 mm deep, and CT provided information on the material distribution across the compacts and showed the areas of locally high density gradients. Thus it has been established that ultrasonic evaluation of green compacts can identify areas which will later end crack and CT shows that these areas are associated with localized high density gradients. Further testing is required to extend results obtained by CT and UT techniques.

ACKNOWLEDGEMENTS

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