Acoustic Emission from Fuel Pellets in a Simulated Reactor Environment

D. S. Kupperman, C. R. Kennedy, and K. J. Reimann, Materials Science Division, Argonne National Laboratory, Argonne, Illinois 60439

ABSTRACT

Thermal-shock damage of nuclear reactor fuel pellets in a simulated reactor environment has been correlated with acoustic-emission data obtained from sensors placed on extensions of the electrical feedthroughs. Ringdown counts, rms output data, and event-location data has been acquired for experiments carried out with single pellets as well as multiple pellet stacks. These tests have shown that acoustic-emission monitoring can provide information indicating the onset and the extent of cracking.

INTRODUCTION

A study has been conducted to investigate the potential application of acoustic-emission technology to the characterization of thermal-gradient cracking in UO_2 pellets. The direct electrical heating (DEH) apparatus described in Ref. 1 simulates in-reactor temperature gradients and heating rates. The objective of the DEH experiments is to develop a capability that can be used to study the effects of heating nuclear fuel pellets. The advantage of acoustic-emission monitoring is that it may provide real-time information on the cracking process that cannot be obtained by other means.

EXPERIMENTAL

Figure 1 is a schematic diagram of the DEH apparatus used for ac acoustic-emission monitoring. The tungsten heat shield shown is not present during the accumulation of acoustic-emission data. The UO_2 fuel pellets used in these tests are 0.6 cm to 1.0 cm in diameter and 1.0 cm long. Single pellets or stacks of four or five pellets were used. Two acoustic-emission monitors were attached to the extensions of the upper and lower electrical feedthroughs of the DEH apparatus.

A commercially available acoustic-emission locator and a signal processor were used to sense the emissions from the pellet stack. The locator

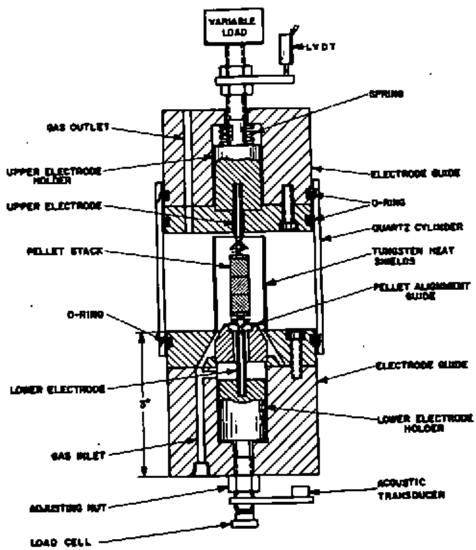

Fig. 1 Schematic of the DEH apparatus used in the present studies.

detects and displays acoustic-emmission events that occur between the two sensors. The sensors used here have a resonance frequency of 175 kHz. A continuous record of the root-mean-square (rms) value of the amplified and filtered acoustic-emission signal from the lower transducer is also maintained. The ends of a pellet stack are defined on the locator screen by striking the electrodes (to simulate acoustic events) above and below the pellet stack before placing the quartz cover over the system. The summation of ringdown counts is obtained from the lower transducer in single-pellet experiments.

During all DEH testing, a continuous record of the pellet-surface temperatures was maintained. Pellet-surface temperatures were measured by means of an infrared optical pyrometer.

Posttest examinations of the pellets heated to temperatures as high as 1700°C were conducted by polishing the ends of individual pellets and observing the cracking patterns under a 16-power microscope or fracturing the pellets; after a fluorescent dye penetrant was used, to reveal the crack-surface area.

RESULTS AND DISCUSSION

Multiple-pellet tests

In the first test, the acoustic-emission count rate versus time and the temperature versus time was monitored for a pellet stack heated to $\sim$1400°C in 150 s. The initiation of significant acoustic emission, and thus cracking, occurred at $\sim$600°C. During the steady temperature phase of the test, acoustic-emission activity was quite low. After turning the current off for rapid cooling, a relatively intense but short period of acoustic-emission activity was observed. This test produced useful information on acoustic-emission activity and crack initiation but did not provide information concerning the relative location of the source of acoustic-emission activity.

When the two-transducer method is used, the relative location of acoustic-emission events can be obtained.

Figure 2 shows the histogram for acoustic-emission events accumulated during heating and cooling phases of a five-pellet stack. Each pellet is represented by two bars in the histogram.

One observes that the acoustic-emission activity is indeed concentrated within the pellet-stack limits, as determined by the calibration procedure. Significantly more acoustic emissions, and thus cracking, is indicated in the upper pellets than in the lower portion of the stack.

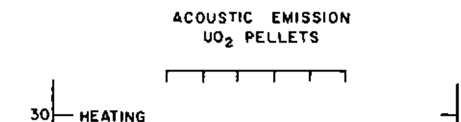

Fig. 2 Acoustic-emission events as a function of location for a five-pellet UO_2 stack.

Post-test examination supported the acoustic-emission results. The upper pellet disintegrated upon removal from the DEH apparatus, but the remaining pellets were intact and were, in general, of uniform crack density.

As a result of the initial large temperature gradient at the electrodes, acoustic emissions are generated near the ends of the stack. Thus, when effects of temperature cycles on cracking are analyzed, it is important to discard data obtained from the two end pellets in the stack because the behavior of the end pellet is somewhat anomalous.

Acoustic-emission monitoring of the fuel pellets would be particularly useful if the extent of cracking in a given pellet was associated with the number of acoustic-emission events. In fact, for pellets with similar types of cracking patterns, a reasonable correlation can be made with the total number of acoustic-emission events and the extent of cracking. The extent of cracking was established by measuring the total length of cracks visible from both ends of the pellet after posttest polishing and examination. The correlation of acoustic emission with crack density for the multiple-pellet tests has been confined to pellets with similar cracking, i.e., primarily radial cracking.

Figure 3 shows the results for 23 pellets, in which the total number of acoustic-emissions events for a given pellet have been plotted versus the average total crack length (in mm) measured on the pellet face. The variation in crack density is the result of changing the maximum temperature and heating rate of the pellets. The correlation between total crack length and total acoustic-emission events for a pellet shows reasonable correlation, considering the complexity of the cracking patterns, and supports the suggestion that acoustic emission can be useful in monitoring thermal-gradient cracking.

The recording of acoustic-emission activity has also been shown to be useful in monitoring thermal-shock cracking of pellet stacks during power transients.(2) In these tests, the apparatus is used to simulate in-reactor loss-of-flow (LOF) conditions and verify escape-path mechanisms. These tests have been run in a modified DEH apparatus using the same transducer configuration shown in Fig. 1.

Significant acoustic-emission activity is present during intervals of large temperature gradients (heating and cooling). These results suggest that cracking occurs during rapid power transients prior to gross melting. Again, acoustic-emission monitoring provides information that cannot be obtained by other methods.

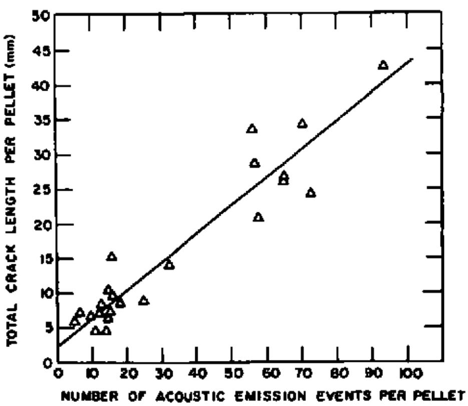

Fig. 3 Total number of acoustic emissions per pellet vs total crack length measured from the ends of the pellets in posttest examination.

Single-pellet tests

As indicated by the multiple-pellet stack tests, complex and extensive cracking patterns in UO_2 fuel pellets can to some extent be characterized by the amount of acoustic-energy generated during crack formation. To understand more thoroughly the correlation between acoustic emission and cracking, single-pellet tests were run. In these tests, the pellet was heated slowly until the onset of acoustic-emission signals, then cooled. As a result, a minimum amount of cracks were generated.

Ten pellets were heated in the DEH apparatus, with the number of cracks varying considerably. All pellets were monitored via the rms circuit, and four were also monitored using the ringdown technique. After the tests were completed, a fluorescent dye penetrant was used to fill the crack and coat the crack surfaces. The pellets were then broken to reveal the penetrant and obtain an estimate of crack-surface area. The uncertainties associated with this technique are reasonably large. However, despite the complexity of the crack patterns and the problems associated with estimating the area of these irregular cracks, a clear trend is evident when data on the crack area and rms signal are compared. Figure 4 shows the results of these experiments. A least-squares linear fit to the data is shown. The coefficient of correlation is 0.87.

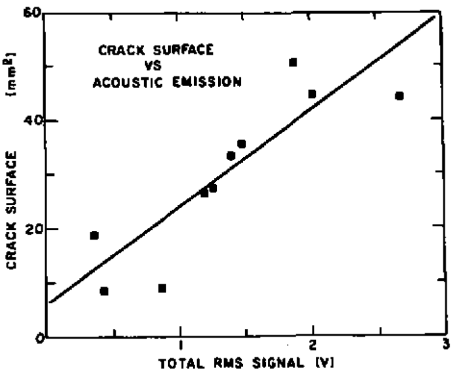

Fig. 4 Crack-surface area vs total rms signal from acoustic-emission monitor. Single pellets were thermally cycles in the DEH apparatus to generate the cracks.

The total rms signal from acoustic emissions has also been correlated with total crack length. A reasonable correlation was also found between crack length and rms signal. Although a more accurate representation of the crack should be obtained by measuring the crack surface, the problems inherent in determining crack surface appear to reduce the correlation between area and acoustic-emission signal to the extent that it is comparable to the correlation between crack length and rms signal. Ringdown counting was monitored for four single-pellet tests. The summation of counts was observed as a function of total crack length and total surface area. For pellets with limited cracking, where rms is still observable, no counts are accumulated because of the counting threshold level. For pellets with larger cracks and stronger signals, the threshold is exceeded and counts are accumulated. The data suggest that, for severe cracking, count accumulation may result in better correlation with pellet damage than rms signals. More work is needed to accurately assess the correlations possible between acoustic-emission and thermal-gradient cracking.

REFERENCES

(1) B. J. Wrona, J. T. A. Roberts, E. Johanson, and W. D. Tuohig, *Nucl. Tech.* (1973) 20 114.

(2) D. D. Marchant, "Thermal-shock Cracking in UO_2 during Power Transients," presented at Winter Meeting of American Nuclear Society, Nov. 16-21, 1975, San Francisco, Calif.