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ACOUSTIC EMISSION BEHAVIOR OF
ZIRCALOY-2 PRESSURE TUBING
UNDER APPLIED STRESS

T. E. Michaels

and

M. C. Fraser

September, 1967

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PRESSURE TUBING UNDER APPLIED STRESS

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UNDER APPLIED STRESS

T. E. Michaels and M. C. Fraser

ABSTRACT

The acoustic emission of Zircaloy-2 pressure tube material was studied during burst tests. Three material conditions were studied; as-received pressure tube material, as-received with addition of 275 ppm hydrogen, and irradiated material.

INTRODUCTION

The determination of the fracture properties of Zircaloy-2 reactor pressure tubing under typical operating conditions could be aided markedly by obtaining more data from each tube specimen. In the determination of hoop stress at failure versus crack length, the present method requires one specimen for each data point produced. For irradiated tubing it is often impossible to catalog a complete relationship because a limited number of specimens exist for a given irradiation exposure level. If the test of a flawed tube could be halted immediately prior to failure and extrapolation made to an approximate failure pressure, the flaw could then be enlarged and another test could be conducted on the same specimen. In this way it might be possible to construct the entire curve of stress versus crack length at failure from a single specimen.

During the deformation process, energy is released in the form of lattice vibrations. This energy is propagated through the metal in the form of longitudinal and associated shear waves and is defined as the acoustic emission phenomena. Vibration pickup devices can be set into oscillation in response to this energy by fluid coupling them to the surface of the material. When the background noise is carefully filtered and controlled, the information from the pickup device can be related to the deformation processes occurring.

Schoefield and others listed in the bibliography have developed acoustic emission monitoring techniques using accelerometers as pickup devices. The accelerometer technique was applied to typical burst tests at Pacific Northwest Laboratories, but operational test noise was much greater in amplitude than any significant acoustical emission signals. However, it is generally known that frequencies as high as

15 MHz can be propagated through most metallic substances. The work reported here is the monitoring of burst tests of autoclaved, autoclaved and hydrided, and irradiated Zircaloy-2 reactor pressure tubing in the frequency range of 50 kHz to 1 MHz. The incentive is that the operational test noise which competes with signal reception at lower frequencies is less of a problem in the higher frequency ranges.

SUMMARY AND CONCLUSIONS

An acoustic emission monitoring technique was applied to burst tests of Zircaloy-2 pressure tubing. Autoclaved (18% nominal cold work), autoclaved and hydrided, and irradiated tube specimens containing artificial flaws were monitored during pressurization to study the acoustic emission generated during the failure process.

Considerable signal was received over a bandwidth of 50 kHz to 1 MHz for the three material conditions tested. In general, the less ductile the Zircaloy-2, the greater the acoustic emission activity. Also, the acoustic emission activity increased substantially as failure was approached for the three material conditions studied. The acoustic emission activity at failure for the autoclaved specimen was approximately 148 pulses per second; the hydrided specimen had a failure pulse rate above 250 pulses per second; and the irradiated specimen had a failure pulse rate over 500 pulses per second.

The pulse rate increased substantially before failure for all three material conditions studied. Using

this pulse rate information, it is possible to halt the test of a flawed tube short of failure and extrapolate to an approximate failure pressure. When the flaw is enlarged and additional tests are conducted, an entire curve of flaw-length versus stress-at-failure might be constructed from one specimen. Although still in preliminary stages, such a technique is especially valuable in determining the burst test properties of irradiated tubing where the number of specimens having a given level of exposure is limited.

DISCUSSION

DEVELOPMENT OF EQUIPMENT

The accelerometers used in preliminary tests at Pacific Northwest Laboratories resonated at their natural frequency of about 30 kHz in response to signal frequencies from 20 kHz to several megacycles. In an effort to raise the upper limit of frequency response, piezoelectric transducers with a resonance frequency of 15 MHz were used as a pickup device in monitoring a crack propagation test on a double cantilever beam specimen of Zircaloy-2 that was machined out of a section of reactor tubing. The results were promising: information as high as the resonance frequency of 15 MHz was received from the transducer as the specimen was failed in tension.

The single pulse information in the higher frequencies had to be conditioned before it could be recorded for analysis because it exceeded the frequency response of ordinary recorders.

An instrument was obtained having a voltage gain variable from 1 to 1 to 5000 to 1, a bandwidth control in half decade steps from 1 kHz to 10 MHz, and circuitry to stretch pulse information linearly as much as 10,000 times the original pulse duration. For the tests reported here, the bandwidth studied ranged in frequency from 50 kHz to 1 MHz. This instrument was used in conjunction with a seven channel data tape recorder so that tests could be recorded and played back for analysis at a later time. Because the higher frequency components were not within frequency response range of the tape recording equipment, the information was stretched and then recorded. Figure 1 is a photograph showing how this

stretching process affects a packet of high frequency pulse information. Figure 2 is a block schematic of the monitoring system. At the time of the test, the information can be monitored on an oscilloscope, recorded on a strip chart, and stored on a magnetic tape simultaneously.

A piezoelectric transducer was used as the pickup device. A 20 to 1 gain preamplifier is placed in line immediately following the transducer to prevent attenuation in the lead from the transducer to the monitoring instrument. The instrument noise level of the combined system of the transducer preamplifier and the stretch-amplifier instrument is equivalent to 25 μ V at the transducer.

Trace (a)

Trace (b)

FIGURE 1. Characteristics of the Pulse Stretcher. Trace (a) is the Stretched Response to Trace (b) Using a Time Resolution of 20 Microsecond per Centimeter

FIGURE 2. Acoustic Emission Monitoring System

EXPERIMENTAL PROCEDURE

Burst tests conducted on three different material conditions of Zircaloy-2 were monitored using the described instrumentation system. The material conditions tested were: (1) as-received material (18% nominal cold work) that was autoclaved, (2) same as (1) except that 275 ppm hydrogen was added, and (3) irradiated material with an exposure of approximately 15 months in reactor.

The autoclaved material and the autoclaved and hydrided material were

both burst at room temperature. The irradiated specimen was submerged in water and burst at 12 °C. A milled slot approximately 3 in. long, 1/16 in. wide, and extending 75% through the wall thickness of the tubing was placed in each specimen.

The circuit voltage gain was approximately 5000 to 1 total for all three tests.

ACOUSTIC EMISSION CHARACTERISTICS

The results obtained from the Zircaloy-2 as-received, autoclaved

reactor pressure tube are shown in Figures 3 and 4. The signal was rectified and stretched 10 times the original pulse duration and then recorded at 60 in. per sec (ips). The playback was performed at 1 7/8 ips so the strip chart recorder would respond to these short duration bursts. Patches of the actual output from the 1 7/8 ips playback are shown in Figure 3. The nominal pulse rate was on the order of 10 pulses per sec from the initial pressurization to about 4300 psi, see Figure 4. From 4300 psi to failure at 4431 psi, the pulse rate increased from 10 pulses per sec to 148 pulses per sec. The pulse rate was determined by counting the pulses from the 1 7/8 ips playback. The shift of dc voltage level toward the end of the test occurs as the pulses come into the stretcher circuit faster than they decay off.

Figures 5 and 6 show the results from tests performed on the hydrided material. The 1 7/8 ips playback for the results obtained on the autoclaved, hydrided pressure tube is shown in Figure 5. Figure 6 shows the real time playback and the pressure-time and pulse rate-time curves for this test. The nominal pulse rate was on the order of 10 pulses per sec from starting pressure to 3400 psi. From 3400 psi to 3870 psi at failure, the pulse rate increased from 10 pulses per sec to above 250 pulses per sec.

The results obtained from the burst test on the irradiated material are shown in Figures 7 and 8. Figure 7 shows the 1 7/8 ips playback results of the test, and Figure 8 shows the

results of the 60 ips playback and the pressure-time and pulse rate-time curves for this test. The pulse rate had a nominal value of 40 pulses per sec up to 4000 psi. From here to failure, there was a steady increase in pulse rate to over 500 pulses per sec at failure.

Figure 9 is a plot of pulse rate versus percent of ultimate pressure for the three conditions of the material tested. Note that in all the tests there was a definite increase in pulse rate as failure was approached. Note also that the pulse rate shows a dependency upon material condition. The irradiated material produced more acoustic emission than the hydrided material which, in turn, produced more acoustic emission than the autoclaved material.

ANALYSIS

The instrumentation set up appeared to be sensitive to signals as low as 25 μ V at the transducer. The nominal signal level was 200 μ V. The nominal background noise level was approximately 25 μ V over a bandwidth of 50 kHz to 1 MHz. In the lower frequency ranges, below 30 kHz, the noise level was found to be approximately 400 μ V during nominal operating conditions. Practical tests are feasible if the signal-to-noise ratio is substantially greater than unity for the bandwidth monitored. Such was the case for the Zircaloy-2 material studied.

The dramatic increase in pulse rate prior to failure indicates that the signals received possibly can be related to the deformation behavior of

FIGURE 3. Acoustic Emission of As-Received Zircaloy-2

FIGURE 4. Acoustic Emission of As-Received Zircaloy-2

FIGURE 5. Acoustic Emission of Hydrided Zircaloy-2

FIGURE 5. *Acoustic Emission of Hydrided Zircaloy-2*

FIGURE 6. Acoustic Emission of Hydrided Zircaloy-2

FIGURE 7. *Acoustic Emission of Irradiated Zircaloy-2*

FIGURE 7. Acoustic Emission of Irradiated Zircaloy-2

FIGURE 8. Acoustic Emission of Irradiated Zircaloy-2

FIGURE 9. Pulse Rate Versus Percent Ultimate Failure for Zircaloy-2 Pressure Tube Material

the material. This hypothesis is further supported by the fact that the pulse rate varied remarkably from one material condition to another, supposedly due to changes in the deformation behavior. If we attribute the signal to dislocation breakaway and mechanical twinning, it seems reasonable that the hydrided material would

respond greater acoustically than the unhydrided material. Compared to unhydrided material, the hydrided material should exhibit more dislocation breakaway and mechanical twinning events in the deformation process resulting in failure. Therefore, based on our hypothesis, the hydrided material should respond greater acoustically.

This same hypothesis can be used to explain the increased acoustic emission activity observed in the irradiated condition as compared to the as-received or hydrided material conditions. The effect of the neutron flux exposure on this material is to produce internal defects which block dislocation motion to a much greater extent than does the 275 ppm hydrogen concentration. It is believed that this accounts for the high increase in pulse rate observed for the irradiated material as compared to the as-received and hydrided material.

The pressure values reported in this report can be converted to approximate hoop stress values by use of the Lamé thick wall formula. The approximate conversion factor is 6.0 for the geometry of the pressure tubes tested.

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