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Acoustic Emission Investigation of Sub-Critical Crack Growth in Zr-2.5 Nb

K. Tangri, Metallurgical Sciences Laboratory

University of Manitoba, Winnipeg, Manitoba, R3T 2N2, Canada

INTRODUCTION

A form of "hydride cracking" is believed to be responsible for the subcritical crack growth in cold-worked Zr-2.5 Nb reactor pressure tubes. From measurements of crack lengths after fracture of static loading of fatigue pre-cracked compact-tension specimens, Simpson and Nuttall (1) have measured average crack velocities (V) as a function of crack tip stress intensity (k_I), temperature and hydrogen content. Their results show that crack propagation occurs at average velocities ranging from 10^{-9} to 10^{-11} m/sec depending upon the test variables. This post-mortem type of technique, by itself, is obviously unsuitable for developing a detailed understanding of the fracture mechanism and its kinetics. For example, it is necessary to employ a dynamic technique to determine if the crack growth is continuous or intermittent. A further advantage of such a technique would be that the effect of changing variables can be measured continuously with greater reliability and economy. In view of the above, we have attempted to employ acoustic emission (AE) technique for investigating sub-critical crack growth in Zr-2.5 Nb containing 10 μg/g of hydrogen.

EXPERIMENTAL TECHNIQUES

To select appropriate AE testing conditions, an estimate of the emission count rate ($\dot{N}$) expected at crack velocities of the order of 10^{-10} m/sec is desirable. Based on the reasonable assumption (2) that $\dot{N} \propto V$, extrapolation to $V = 10^{-10}$ m/sec of the data of other investigations at crack velocities of 10^{-2} - 10^{-6} m/sec predicted an expected $\dot{N}$ of about 10 count/Hour. The AE monitoring system selected in view of the small $\dot{N}$ expected is shown in Fig. 1 which is self-explanatory. AE activity was monitored with a high temperature (range up to 540°C) differential Dunegan-Endevco transducer D9205M2 (0.1-0.2 MHz) affixed to one large face of the test specimen. The specimen was brought to temperature under a small load imposed by a weight pan in a lever-loading arrangement. The temperature was maintained at any desired level to within ±2°C and necessary load applied to yield a desired k_I value at the crack tip. The number of times the AE signal exceeded a fixed threshold was counted to produce a continuous plot of cumulative counts (ΣN) vs time on a X-Y recorder. Filter band width of 0.1-0.4 MHz and a total gain of 95 dB was employed throughout this test series.

RESULTS

To determine the ambient and equipment background noise ($\dot{N}_D$), a dummy sample maintained at 126°C was monitored for 24 hours. As $\dot{N}_D$ was found to vary between 20 and 50 counts per hour, an average value of 35 count/Hour may be assigned to $\dot{N}_D$. The dummy sample was then replaced by a compact-tension specimen under identical conditions and the resulting AE monitored for about three days. A typical segment of ΣN vs time plot is given in Fig. 2 which shows sharp AE bursts of varying magnitudes randomly spaced in time. We will assume that these bursts are due to hydride cracking (crack growth). This is a plausible assumption, since the ductile zirconium matrix is expected to be relatively "quiet" as compared to the noisier cracking of the brittle zirconium hydride. A histogram of the "bursts" (cracking events) for the first 61 Hrs of this test is shown in Fig. 3. Average values of the AE background count rate ($\dot{N}_B$) associated with these bursts are also shown on the histogram.

After the three day test at 126°C, the temperature of the specimen was raised in steps up to 225°C and AE monitored for 24 hour periods at each temperature. The results, given in Fig. 4, show that the frequency of AE bursts decreases with increase in temperature till no bursts are present at 225°C. From their fractographic studies on the static loaded compact-tension specimens of this material under similar test conditions, Simpson and Nuttall (1) have shown that crack growth rate decreases as hydride is taken into solution and that crack growth is stopped at ∿225°C. This agreement between the AE and fractographic studies supports our assumption that the observed AE bursts are due to hydride cracking.

After the above tests, specimen temperature was reduced and AE monitoring continued at 126°C for a further period of 4 days. The results are shown in Fig. 5. To determine the count rate associated with cracking events, AE monitoring was continued for another eight hours employing a faster time base on the X-Y recorder. A typical ΣN vs time trace is shown inset in Fig. 2. Average count rates of about 10^5 to 10^6 per Hour were observed. At the end of this series of tests, the specimen was replaced by the Dummy sample and monitoring continued for two days. The final $\dot{N}_D$ values were found to vary between 500 to 700 counts/Hour.

DISCUSSION AND CONCLUSIONS

1. From the agreement between fractographic studies and the AE results at different temperatures, as shown in Fig. 4, it may be concluded that the observed AE bursts are due to hydride cracking during sub-critical crack growth of Zr-2.5 Nb. The count rates associated with these cracking events are two to three orders of magnitude greater than the general AE background ($\dot{N}_B$).
2. From Figs. 2-5, it is seen that sub-critical crack growth is a discontinuous rather than a continuous process.
3. Comparison of Figs. 3 and 5 shows that the frequency of cracking events and the number of AE counts associated with an event (N_C) is, on the average, considerably greater in the second than in the first test period. Though k_I values increase as the test and as such the crack progresses, the crack velocity (3.2 x 10^{-9} m/sec for our material and test conditions - as determined by L.A. Simpson of WNRE) is marginally affected by the magnitude of k_I variation encountered in the test conditions involved here (1). These experimental observations suggest that as crack growth proceeds, the number of hydride particles failing during a given crack increment increases. Furthermore, as the crack velocity is essentially constant, the increase in frequency of cracking events suggests that hydride cracking is also initiated at other sites behind the advancing initial crack.
4. From Figs. 3 and 5, it may be noted that the background count rate ($\dot{N}_B$) increased from 25-150 counts/Hour in the first test period to 150-500 counts/Hour in the second test period. Moreover, the variation in $\dot{N}_B$ within any time interval did not coincide with the incidence of cracking events. Furthermore, the count rate with the Dummy sample ($\dot{N}_D$) increased from 20-50 counts/Hour at the

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beginning of the test to 500-700 counts/Hour at the conclusion of the test. From these observations, it is concluded that equating an average noise count rate based on tests before and/or after an extended AE test with the actual noise count rate during such a test has little meaning. Thus, to make AE technique useful for quantitative studies of sub-critical crack growth, it is necessary to develop techniques for dynamic subtraction of background noise from the true AE signal. Work towards this end is now in progress in our laboratory.

REFERENCES

(1) L.A. Simpson and K. Nuttall, *Quebec City. ASTM Symposium on Zirconium* (August 1976); (2) A.G. Evans and M. Linzer, *J. Amer. Ceram. Soc.* (1973) 56 575.

ACKNOWLEDGEMENTS

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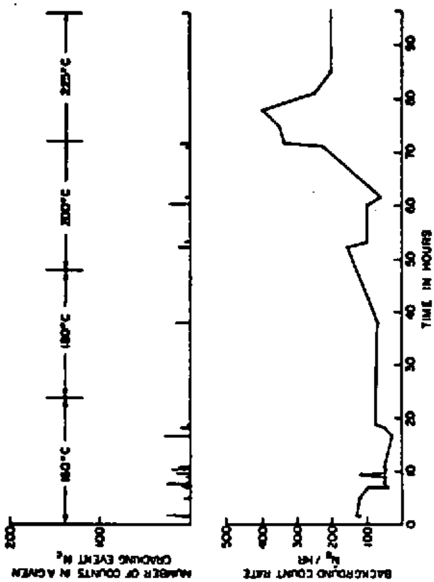

Fig 4. EFFECT OF TEMPERATURE ON AE ACTIVITY IN SPECIMEN KTSB. TEST PARAMETER SAME AS Fig 2.

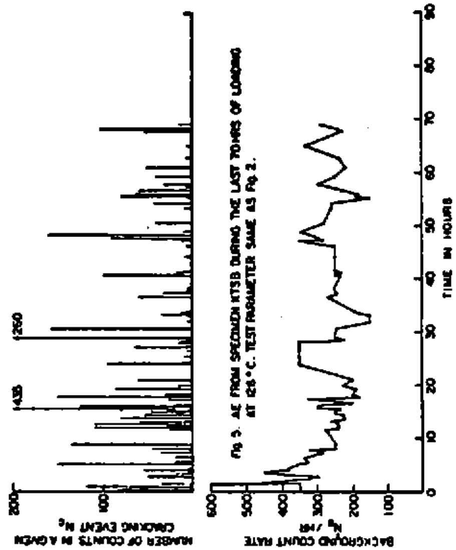

Fig 5. AE FROM SPECIMEN KTSB DURING THE LAST 70 HRS OF LOADING AT 225°C. TEST PARAMETER SAME AS Fig 2.

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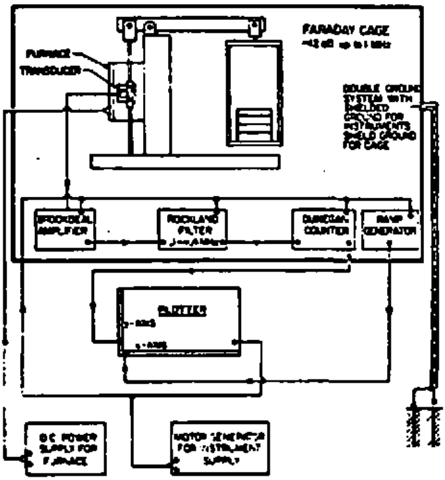

Fig. 1. BLOCK DIAGRAM OF THE AE TEST EQUIPMENT.

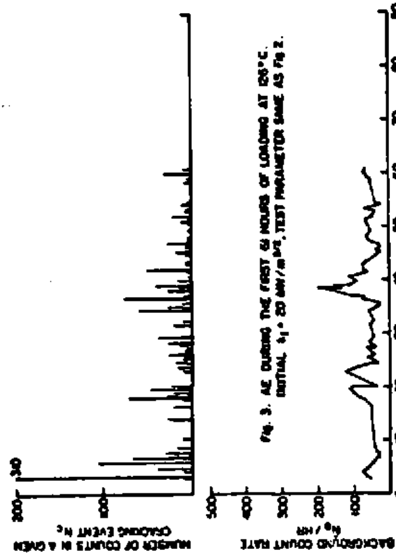

Fig. 3. AE DURING THE FIRST 40 HOURS OF LOADING AT 126°C. INITIAL K = 20 MN/m^3/2, TEST PARAMETER SAME AS Fig 2.

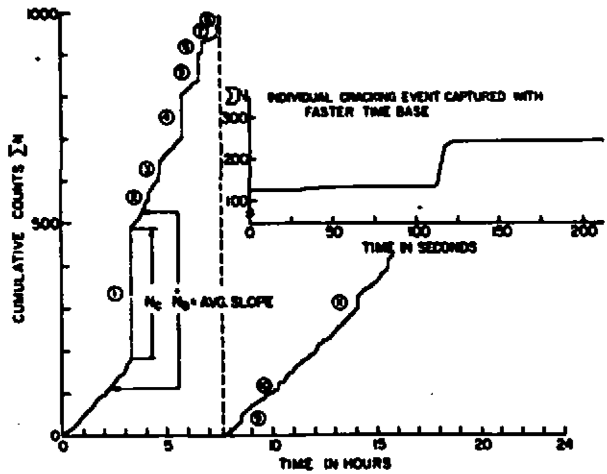

Fig 2 A TYPICAL SEGMENT OF AN AE PLOT ON THE X-Y RECORDER FROM A Zr-2.5 Nb SPECIMEN LOADED AT 126°C. COMPACT TENSION SPECIMEN ®RT58 TRANSDUCER DUNEGAN-ENDEVCO D 9205 M2 BANDWIDTH 0.1 → 0.4 MHz, GAIN 95 dB.