ACOUSTIC EMISSION ANALYSIS OF CRACK PROPAGATION AND FRACTURE IN PRESSURE VESSELS AND PRESSURE VESSEL MATERIALS

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ABSTRACT

This paper presents the acoustic emission data generated and recorded during metal tensile specimen tests, both unflawed and flawed, model concrete pressure vessel tests, and compressive tests of cylindrical specimens. Irradiation, temperature, prestressing, and internal pressurization test results are discussed for the various specimens, as are other factors which affect the acoustic emission response of the material. Parametric relationships between acoustic emission data and other indices of structural performance is presented.

1. BACKGROUND

Since the original efforts of Dr. Kaiser (1) in Germany in the late 1940's and early 1950's when he determined that acoustic emission test techniques could "determine for any specimen whether it had already been subjected to any stress, the magnitude of this stress, and, that it could also be used to determine the elastic limit, yield point, and rupture limit," a great amount of research and development effort has been expended in the United States elaborating on his findings. Acoustic emission techniques have been shown to be one of the most informative methods of determining materials and structural performance currently available. One of the most concentrated applicational developments for acoustic emission is towards assuring the safety and operation of nuclear reactor pressure vessels. This effort stems from previous application towards pressure vessel integrity accomplished in the early 1960's (2). In the majority of the programs being conducted today the primary emphasis has been placed on inspection techniques, instrumentation and system concepts very little effort has been expended in the area of the nuclear pressure vessel material itself, from an acoustic emission viewpoint. The literature lists work performed on graphite (3), zircalloy (4), and concrete (5); however, each of these were primarily directed towards objectives not necessarily relevant to the safety and operation of nuclear reactor pressure

Note: Numbers in parenthesis refer to Reference listed at end of text.

vessels. This paper will present the results of programs where acoustic emission data was obtained specifically towards assuring the above stated objective.

2. INTRODUCTION

Acoustic emissions are the impulsively generated elastic waves created by discrete movements within the volume of the material being stressed. Acoustic emissions can be detected from movements as small as those created by phase transformations within a crystalline structure or from movements as large as the propagation of a fatigue crack under low cycle growth conditions. Acoustic emissions have been detected by the authors in such material as wood, glass, concrete, beryllium, fiberglass, ice, asphatic-concrete, many structural metallic alloys, composite and honeycomb materials. There are many factors which affect acoustic emission in materials (6). There are some materials which are very quiet in terms of acoustic emission amplitude levels, others are exceptionally noisy; also some materials generate acoustic emission copiously while others produce very few emissions. In order for inspection techniques, instruments and systems to be properly developed and utilized for structural integrity assessment, the acoustic emission characteristics of the material utilized must be known.

The detection of acoustic emission is usually accomplished with a piezoelectric crystal sensor coupled to the part under test. The sensors output is amplified through a high gain low-noise preamplifier, filtered in order to remove any extraneous low frequency hardware noise, conditioned (in any of a number of ways) and displayed. Conventional displays of acoustic emission data consist of rate of acoustic emission ($\dot{N}$), total cumulative emission (ΣN) and amplitude of emission versus other parameters such as load, fatigue cycles, temperature, irradiation, pressure, time, etc. With this background we now proceed to look at acoustic emission data obtained during tests on nuclear pressure vessel materials and models.

3. METAL

Acoustic emission data were obtained during the specimen testing of the first capsule removed for evaluation in the Connecticut Yankee reactor pressure vessel surveillance program. This data was acquired in order to determine the difference if any in the acoustic emission response of irradiated versus unirradiated pressure vessel steel. The irradiated specimens, prepared from SA 302, Grade B, reactor vessel steel, were from the 10 1/2-in. thick middle shell. They had been exposed to approximately 550°F and a fast fluence of $2x10^{18}$ n/cm^2 (E > 1 Mev) (7).

Unirradiated specimens of the same heat as the irradiated specimens were not available. Therefore, an unirradiated plate of SA 302, Grade B, 4-in. thick was used for fabricating these specimens. The mechanical properties of both heats of this material in the unirradiated condition were essentially identical. Two specimen configurations were utilized in these tests; the round smooth tensile and the WOL (wedge-opening-loading specimen). In order to obtain a variation in the yield strength of the material and thus evaluate its effect on the acoustic emission, tests were conducted at three nominal temperature levels (i.e., 75, -100, -150°F).

Since the acoustic emission data was being obtained as a secondary objective of a testing program whose primary objective was to determine the mechanical properties of the specimen material; deviations in the standard surveillance procedures were not allowed. Thus, for example, both the tensile tests and the fracture toughness tests were conducted at a crosshead speed of 0.02 inches per minute in a 20,000 lb. capacity, screw driven test machine and therefore variations in strain rate and the resultant effect on the acoustic emission data were not determined. The limited number of specimens contained in the surveillance capsule dictated the number of tests performed.

A diagrammatic representation of the acoustic emission instrumentation is shown in Figure 1. The acoustic emission transducer was placed midway between the mechanical extensiometer attachment points on the smooth tensile specimen. The epoxy shoe of the transducer was machined to fit the radius of the specimen. For the WOL specimen tests a special spring loaded fixture was used which held the acoustic emission transducer directly against the specimen mounted in the cryostat for the various temperature conditions. The load signal was available from the test machine to allow the data to be plotted as a function of load.

The WOL specimens were tested in accordance with the recommended procedures of the ASTM's Committee E-24. The crack-opening-displacement (COD) data was obtained from the double cantalever strain gage beams. Fracture toughness considerations required that these specimens be tested at -100°F and -150°F in order to produce valid plain-strain fracture toughness (K_{IC}) values. Consequently, a liquid nitrogen spray cryostat was utilized in order to produce the required results. Specimen temperature was monitored by a thermocouple spot welded to each specimen. All tests were performed at Battelle Memorial Institute, Columbus, Ohio.

Table 1 lists the various tests conducted together with amplification (in db) and background noise level (in counts/sec). It should be distinctly noted that amplification factors ranged from 80.4 to 96db for the various tests conducted. This point will be further discussed in later paragraphs. The actual test temperatures have been rounded to a temperature value used in the discussion, the difference between actual and discussion test temperatures is not believed to be of significance.

3.1 Smooth Tensile Specimens

The data shown in Figure 2 illustrates the acoustic emission (summation, ΣN) as a function of strain together with the stress-strain diagram for an unirradiated A302B base metal specimen. The acoustic emission rate data ($\dot{N}$) is also displayed. The acoustic emission rate reaches its maximum value before yielding is indicated by the stress-strain data, and decreases sharply at the onset of Luder's yielding. This acoustic emission response differs widely from that previously reported for aluminum, iron-silicon alloy (8), titanium, and high strength steel (9) tensile specimens where the acoustic emission rate reached a maximum after the indication of yield by the stress-strain data. It appears that for this material (A302B) the dislocation buildup during the microstrain region before gross yielding generates considerably more acoustic emission than does the massive dislocation motion during Luder's straining. The absence of significant amounts of acoustic emission data in the work hardening range is consistent with previously reported results (9).

The acoustic emission data obtained from the irradiated base metal and irradiated weld metal specimens are shown in Figures 3 and 4 respectively. Here also we see that the major protion of the acoustic emission data occurs before general yielding. We find that the irradiated specimens produce more acoustic emission than the unirradiated material, and that the irradiated weld metal produces more acoustic emission than the irradiated base metal.

The increase in acoustic emission data of the base metal with irradiation is most likely the result of the radiation induced increase in yield strength. This is consistent with previously reported behavior of annealed and cold worked materials of the same alloy (10).

3.2 Fracture Toughness Specimens

Acoustic emission data as a function of stress intensity factor was obtained on WOL specimens of unirradiated base metal, unirradiated base metal, and irradiated weld metal. The stress intensity (K) at the crack front for a 1x WOL is calculated by the following equation

$$K = \frac{P}{\sqrt{a}} f(\frac{a}{w}) \text{ in psi-}\sqrt{\text{in.}} \qquad (1)$$

where: P is the applied load in lbs.
a is the crack length in in.
w is the specimen width in in.

and

$$f(\frac{a}{w}) = -5.6 + 60.9 (\frac{a}{w}) - 139.3(\frac{a}{w})^2 + 140.9(\frac{a}{w})^3 \text{ inches}^{-1} \qquad (2)$$

For this investigation, plastic zone corrections were not employed.

Based upon previous studies (11) the stress intensity and acoustic emission data obtained from these tests were fit to an equation of the form

$$\Sigma N = AK^n \qquad (3)$$

where: ΣN is the cumulative acoustic emission in total counts
K is the stress intensity factor in KSI - $\sqrt{\text{in.}}$

A and n are constants characteristic of the material. The theoretical model predicts an exponent of 4, and values as high as 8 have been observed on high strength steel and brittle materials such as beryllium (12). It has also been experimentally observed (8) that as the state of stress changes from plain stress to plain strain the value of the exponent n increases.

A best fit of the experimental data to the above equation was performed for each of the seven WOL test specimens and the results are tabulated in Table 3.

The reason for the variation between the theoretical exponent value of 4 and the values obtained from these specimen tests ranging from 0.472 to 2.160 is currently not known. Further work is required to understand why the value of n in this case was lower than observed previously.

The data shown in Figure 5 presents the composite of all WOL specimen tests. Here we see that for a given temperature more acoustic emission is observed from the irradiated base metal than from the unirradiated base metal and similarly from the weld metal. Here again, this is believed to be caused by the increased yield strength of the material in the irradiated condition and is consistent with the observations made from the tensile specimen data. Also consistent with the above observations is the results shown by the data whereby the acoustic emission response is increased as the temperature is decreased. This is apparent even though no adjustments have been made to the data to account for approximately 5db less gain used for the -100°F and -150°F than for the room temperature tests.

The data obtained from these tests varies in one aspect from the acoustic emission results obtained in room temperature tests of base and weld metal specimens. In previous results, almost without exception, weld metal specimens produce more acoustic emission than base metal specimens. This is believed to be primarily due to the cast structure of the weld as opposed to the wrought base material, thereby creating a greater dislocation density in the base metal. In this test program no weld metal specimen either in the irradiated or unirradiated condition were available to compare against the RT base metal test. Additional effort should be expended in this area to better understand this apparent anomaly.

The increase in acoustic emission data with increasing stress-intensity factor is very promising because it indicates that it should be possible to use acoustic emission activity to detect the onset of slow crack growth prior to final, fast fracture in irradiated reactor pressure vessel materials. The effect of strain rate, crack growth rate and other parameters were not evaluated during these tests.

4. CONCRETE

Acoustic emission data was obtained during a program specifically established to evaluate the applicability of acoustic emission to detect the failure and progression of failure in cylindrical concrete specimens and a model prestressed concrete pressure vessel (13). Towards this objective, twelve 6-in. by 12-in. cylindrical concrete specimens consisting of four each of three aggregate materials; one scale model - prestressed concrete reactor pressure vessel and one cylindrical mortar specimen were tested and acoustic emission data recorded together with additional engineering measurements.

Results of this test program, in summary, showed acoustic emission from concrete to be an indicator of failure processes. Early warning of total compressive failure and preliminary correlation to material modulus was indicated. Resolution of gross cracking, onset of pressure vessel failure and leakage, and prestressing rod failure was accomplished. Long term monitoring of time and/or environment dependent effects are a practical application. In addition, the ability to determine previous stress (load) levels due to the irreversible nature of the emissions (Kaiser Effect) can be of use in both full-scale pressure vessels and in such areas as laboratory research on fatigue damage concepts.

4.1 Concrete cylindrical Specimen

The instrumentation system used in these tests is similar to that previously shown; however, all data were also recorded on high frequency magnetic tape. Extensometer measurements were made on the cylindrical specimens in accordance with ASTM Standard Tests. Acoustic emission data, totalized, is shown plotted against the applied load in Figure 6. The transition from slow to accelerating failure is clearly noted at 125,000 pounds of compressive load. The acoustic emission rate data shown in Figure 7 illustrates the irreversible nature of the emission. Data is shown for the first cycle loading to 75,000 pounds at which time load was reduced to zero, the extensiometers removed, and then load reapplied for a second cycle to failure. On the second cycle few emissions are seen until the 75,000 pounds load level is exceeded. Similar results can be shown for multiple cycle tests.

4.2 Model Prestressed Concrete Reactor Vessel

The model prestressed reactor vessel tested in this program is shown in Figure 8. This vessel was one of a series of experimental vessels designed, constructed and tested by Union Carbide, Nuclear Division, at Oak Ridge National Laboratory as part of the Prestressed Concrete Reactor Vessel Program. Acoustic emission data was obtained and recorded during the prestressing operation, after prestressing before test, pressure cycle tests, and prestressing rod failure tests.

When the program was first projected, it was anticipated that acoustic emission could be used during the prestressing operation to detect the emission from the metal prestressing rods. However, it was apparent after the beginning of the test program that the rate and amplitude level of the acoustic emissions from the concrete even at very low stress (loading) levels, would mask any emission such as commonly observed in tests on unflawed metallic structures. Therefore, the application of sensors and the acquisition of acoustic emission data during the prestressing operation was only of academic interest.

In these tests multiple sensors were adhesively bonded directly to both prestressing rod nuts and the exposed faces of the pressure vessel itself. All emission data was recorded on magnetic tape and selected sensor positions had rate of emission data displayed on a strip chart recorder in real-test time. Strain gages which had been applied to selected rods and to designated planes on the pressure vessel were read at various steps in the test procedure.

After the prestressing operation was completed, the pressure vessel was undisturbed for approximately 11 hours during which time acoustic emission rate data was continuously monitored and recorded. The acoustic emission data obtained during this 11 hour period showed that within the first three hours after prestressing had been completed the data assumed a relatively stable rate. Higher peak rate values became fewer and farther between as time progressed. After checking closely to determine that this data was not compromised by instrumentation drift, environmental conditions or other anomalous responses, it was concluded that the acoustic emission data did reflect small reorientations occurring within the pressure vessel and prestressing system itself.

Acoustic emission data acquired during the internal pressurization tests of the mortar, model prestressed concrete reactor pressure vessel also demonstrated the practical use of the Kaiser Effect to determine previously applied stress levels and to detect continuing structural damage. Sensors provided data which showed considerable acoustic emission activity during the first cycle to a given pressure level, with very little emission data upon subsequent cycles to the same pressure level. This was indicative of the results at or below approximately 400 psig. Beyond 400 psig continuing emission activity was noted which indicated continuing structural deformation at this pressure and higher. Pressure vessel head deflection measurements confirmed this observation by showing deviation from linearity at the 400-500 psig region, depicting non-elastic response of the pressure vessel structure at this stress level.

Cracking and pressurization fluid leakage occurred on the model pressure vessel during rising pressure to 900 psig. Visible observance of the crack pattern was corroborated by the increased acoustic emission data from sensors in the cracked regions of the vessel. The acoustic emission data also determined the point in time at which leakage was first observed, also the point when maximum cracking and gross leakage occurred.

Because acoustic emissions are generated from a localized volume within the structure, it is possible through appropriate analysis to locate the origin of structural degradation. At least two methods are available for this purpose. The first method is one that provides a gross indicator of the source of emissions, it relies on the sensors located closest to the degrading structural volume to provide the highest signal level, and is referred to as zoning.

The other technique used in locating the origin of the emissions is triangulation. Since the emissions originate from a specific source, they arrive at each of the various sensor locations at different times depending upon their path distance from the sensor and the velocity of the wave travel in the vessel material. These variations in the time of wave arrival can be measured and used to locate the emission source. Both of the above methods were successfully used during the proceeding tests.

The pressure vessel was not destroyed during pressure testing. Therefore, attempts were made to fail the vessel by planar symmetrical, unsymmetrical, and non-planar skewed prestressing jack arrangements. Large amounts of acoustic emissions were generated during each tensioning application similar to results obtained during the original pressure vessel prestressing operation. During these tests, however, maximum hydraulic jack pressures were applied in attempts to force failure of the pressure vessel itself. While acoustic emissions were generated during each prestressing operation, prestressing rod failures always occurred prior to any pressure vessel gross structural degradation. Large peaks in acoustic emission rate data were created at and/or during prestressing rod fractures.

4.3 Mortar Cylindrical Specimen

In the final experiment a cylindrical specimen of the mortar material used in the model pressure vessel was loaded directly to failure under a rising compressive load, while acoustic emission data, axial and transverse strain data were recorded. Figure 9 shows the acoustic emission cumulative total data simultaneously with the axial and transverse strain. The strain data indicates that a deviation from linearity occurs at approximately 2200 psi. Even with a scale of 10,000 counts per inch, the acoustic emission cumulative total shows what is most likely the first indication of "less than elastic" response at 1500 psi. As noted in other programs, the use of surface-mounted displacement measuring instruments is most likely not as true an indication of nonlinear response as is the more volumetric measurement of acoustic emissions.

4.4 Amplitude Probability and Modulus

The randomly occurring transient nature of acoustic emission makes them difficult to analyze in terms of conventional electronic equipment. However, as an approximation to the varying signal level, fixed rate-pulse height data were obtained for each of the compressively loaded specimens. A statistical distribution showing probability of larger signal levels occurring has been plotted from the average of the specimens of each aggregate type. Figure 10 shows the cumulative probability plot for acoustic emissions recorded during the tests. For comparative purposes, it is interesting to note that the probability of a larger amplitude (say for example 10db) occurring is inversely related to the modulus of the concrete. This is interpreted as being created because of the smaller deformation occurring with the higher modulus material. Since acoustic emissions are phenomenologically related to deformation, it follows that smaller deformations would produce less emission.

5. APPLICATION

If we consider only the variation in acoustic emission amplitude (from among the many characteristics of the emission), it should be obvious that as the amplitude of the acoustic emissions created in the deformation process of the particular part under surveillance become very small; they become increasingly more difficult to detect. Background noise levels may then determine whether or not these signals may be detected during acoustic emission monitoring. In pressurized systems the ability to detect these signals are greatly dependent upon whether or not the system is under static or flowing pressurization. Flow, or other operational system noises, affect the sensor spacing required to detect any particular acoustic emission amplitude level.

In a recent report (10) the sensor spacing required to detect a particular amplitude of signal in A302B pressure vessel steel was determined to be on the order of 19 to 31 inches apart. Through monitoring typical acoustic emission amplitude levels during the testing of both three point bending and stress corrosion test specimens of the A302B pressure vessel steel the minimum amplitude level desired for detection was established. With this amplitude level and the attenuation factor for the material, the required sensor spacing (for static pressure conditions) was established.

6. SUMMARY

This paper has presented data from metal and concrete reactor vessels materials and has shown the effect of irradiation, time, load, temperature, etc., on the acoustic emission response.

Through studies such as these, relationships between, the onset of catastrophic failure and acoustic emission characteristics have been established. However, previous programs have shown that it is necessary to characterize the acoustic emissions associated with fracture for the material conditions and environemnts (media, loading rate, temperature, etc.) unique to each application. This is necessary because of the pronounced effect such variables exert on fracture, the mechanism by which it occurs, and the instrumentation requirements necessary to detect such failures under actual service conditions.

The authors strongly stress simultaneous development of acoustic emission characterization of reactor pressure component materials and the nondestructive inspection systems which will utilize this information, for without this knowledge, the complete success of acoustic emission techniques may not be realized.

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TABLE 1. ACOUSTIC EMISSION VARIABLES AND TEMPERATURES FOR TENSILE AND WOL TESTS

Material	Test	Temperature, °F		Gain	Background
		Actual	Discussion	(db)	(counts/sec)
Unirradiated A302B Base	Tensile	75	Room	95	10
Irradiated A302B Base	Tensile	90	Room	96	10
Irradiated A302B Weld	Tensile	90	Room	96	10
Unirradiated A302B Base	WOL	75	Room	85	10
Unirradiated A302B Base	WOL	-94	-100	85	<100
Unirradiated A302B Base	WOL	-142	-150	85	<100
Irradiated A302B Base	WOL	-100	-100	80.4	50
Irradiated A302B Base	WOL	-159	-150	83.6	400
Irradiated A302B Weld	WOL	-102	-100	80.4	400
Irradiated A302B Weld	WOL	-159	-150	80.4	500

TABLE 2

TEST SPECIMEN ASSIGNMENT

TEST	TEMPERATURE	MATERIAL			
		UNIRRADIATED		IRRADIATED	
		A302B		A302B	
		BASE METAL	WELD METAL	BASE METAL	WELD METAL
Tensile	75°F	X		X	X
WOL	75°F	X			
WOL	-100°F	X		X	X
WOL	-150°F	X		X	X

TABLE 3

Acoustic Emission, Stress-Intensity Data fit to $\Sigma N = AK^n$
(Lease square computer fit)

MATERIAL	TEST TEMPERATURE (°F)	A	n	Index (Degree of Fit) 1.0 = Perfect
Unirradiated				
Base	75	1.06×10^{-6}	2.160	0.874
Base	-100	1.51×10	0.854	0.993
Base	-150	2.169×10^2	0.665	0.998
Irradiated				
Base	-100	1.97×10	1.022	0.983
Base	-150	3.70×10^{-1}	1.488	0.990
Weld	-100	9.23×10	0.766	0.996
Weld	-150	1.815×10^3	0.472	0.995

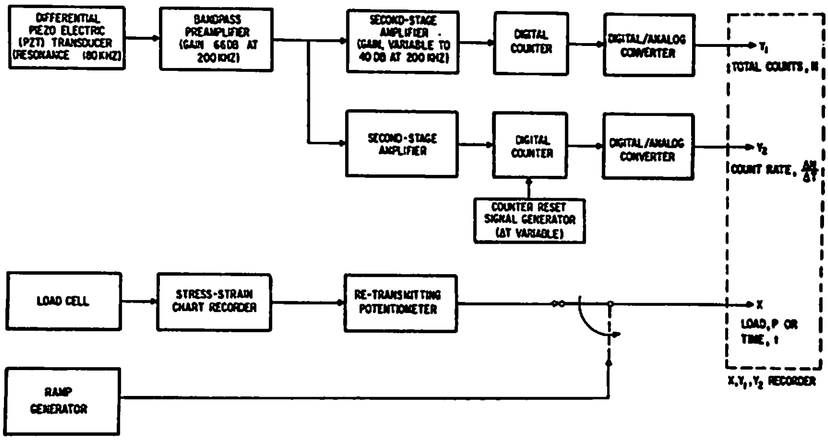

FIGURE 1. DIAGRAM OF ACOUSTIC EMISSION SYSTEM

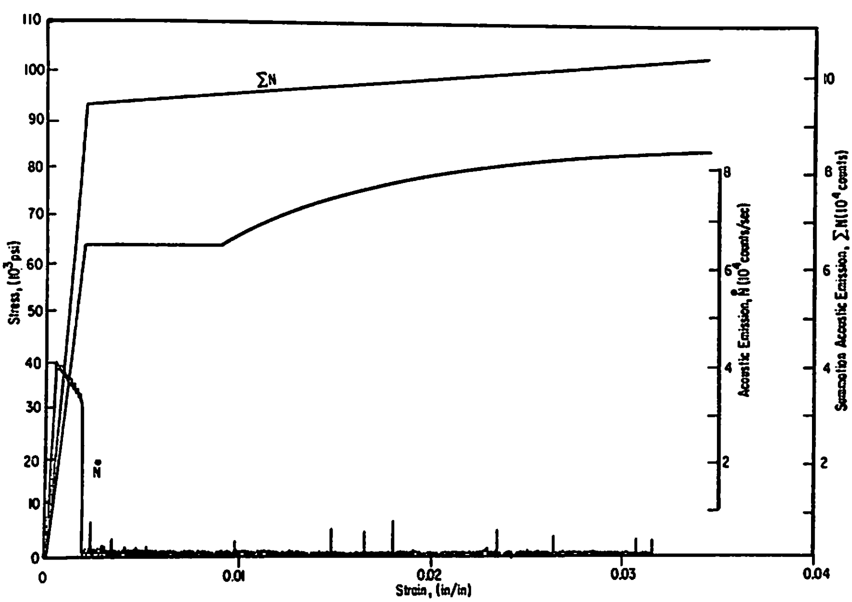

FIGURE 2 ACOUSTIC EMISSION AND STRESS AS A FUNCTION OF STRAIN FOR AN UNIRRADIATED TENSILE SPECIMEN OF A302B BASE METAL

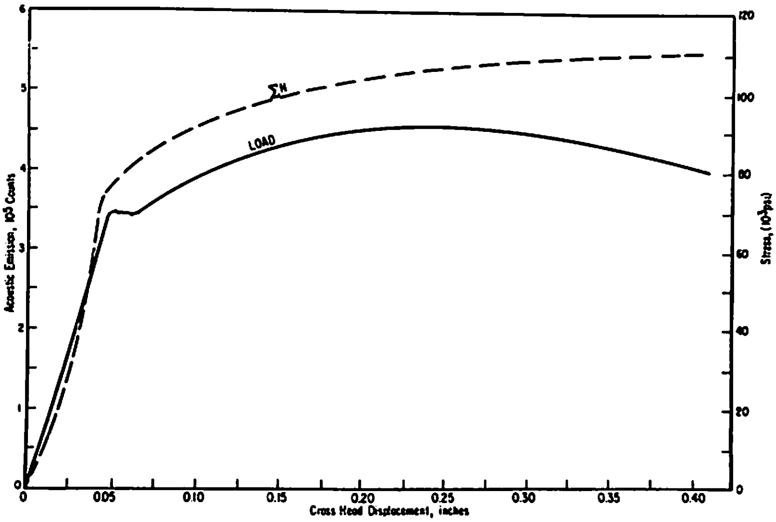

FIGURE 3 SUMMATION ACOUSTIC EMISSION AND LOAD AS A FUNCTION OF CROSS-HEAD DISPLACEMENT FOR AN IRRADIATED TENSILE SPECIMEN OF A302B BASE METAL

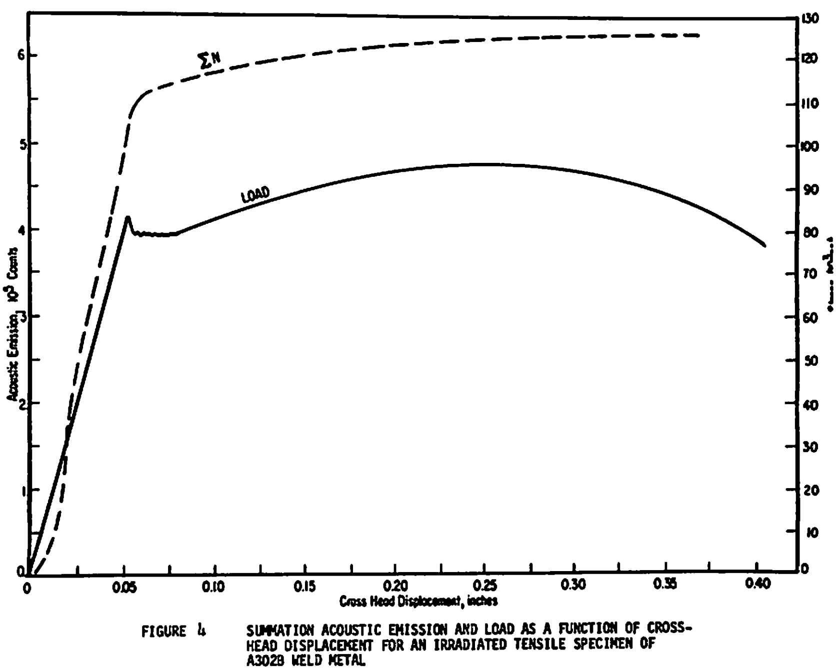

FIGURE 4 SUMMATION ACOUSTIC EMISSION AND LOAD AS A FUNCTION OF CROSS-HEAD DISPLACEMENT FOR AN IRRADIATED TENSILE SPECIMEN OF A302B WELD METAL

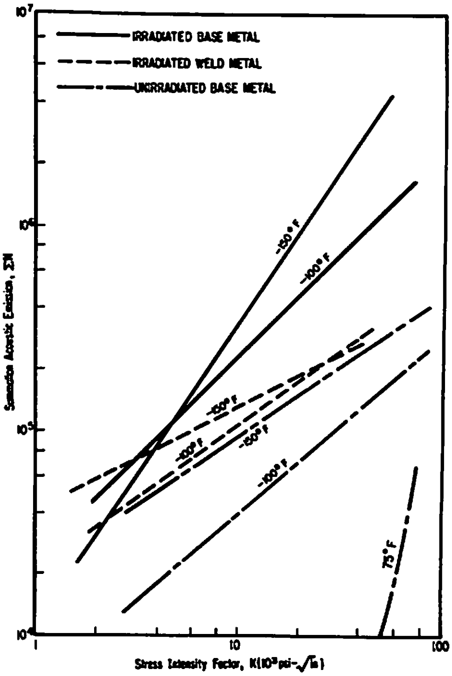

FIGURE 5 SUMMATION ACOUSTIC EMISSION AS A FUNCTION OF STRESS INTENSITY FACTOR FOR WOL SPECIMENS OF A302B AT THE INDICATED TEST TEMPERATURES

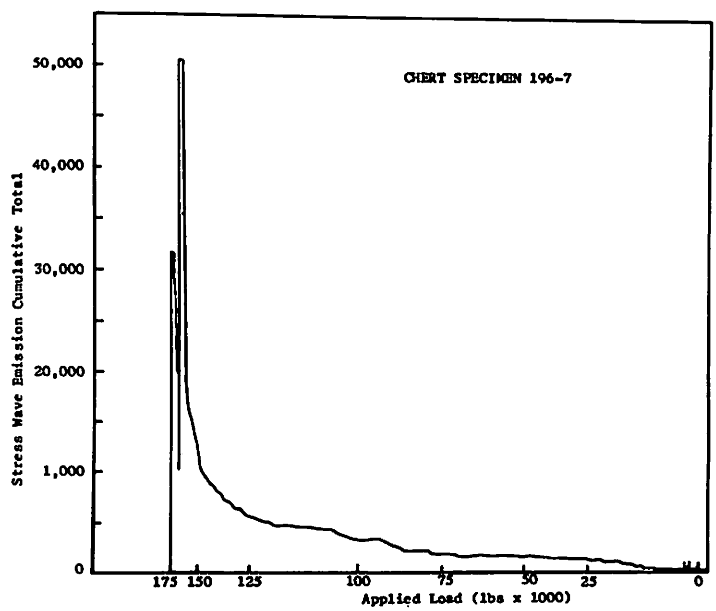

Figure 6 Stress-Wave-Emission Cumulative Total vs Applied Load, Specimen 196-7

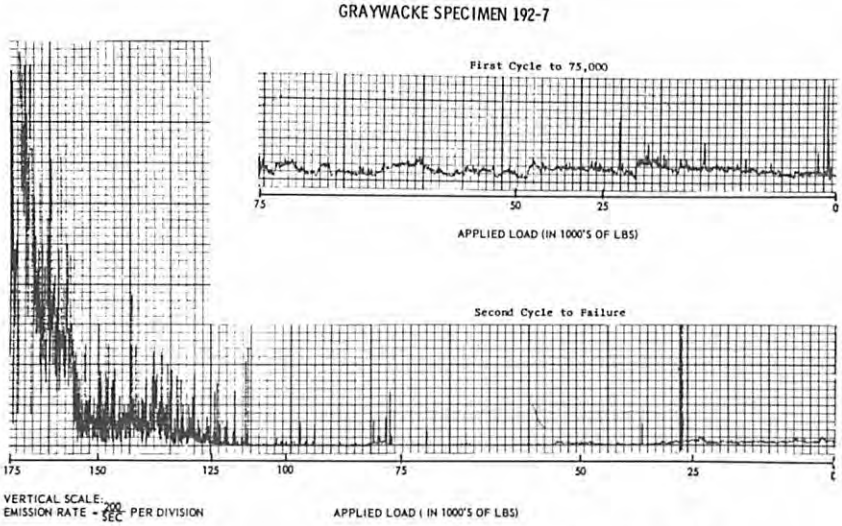

Figure 7 Stress-Wave-Emission Rate vs Applied Load, Specimen 192-7

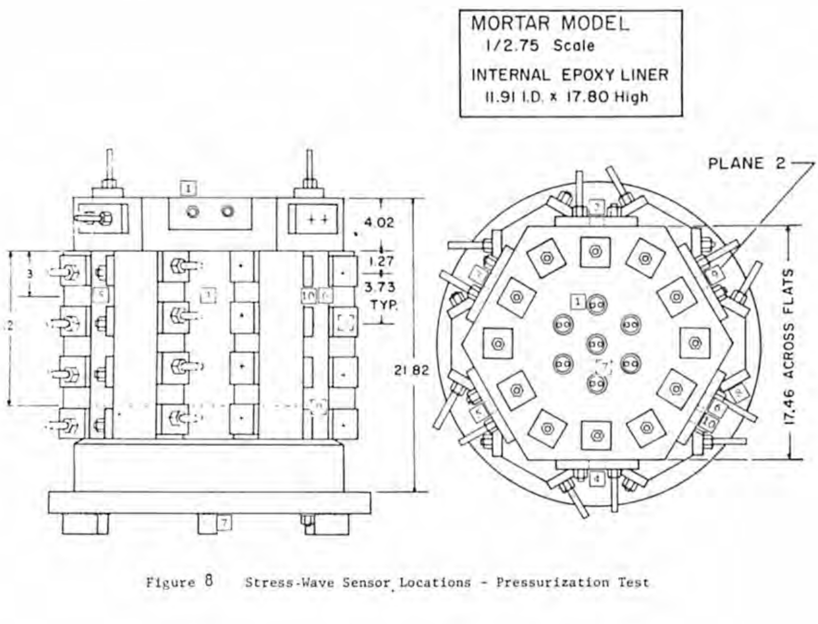

Figure 8 Stress-Wave Sensor Locations - Pressurization Test

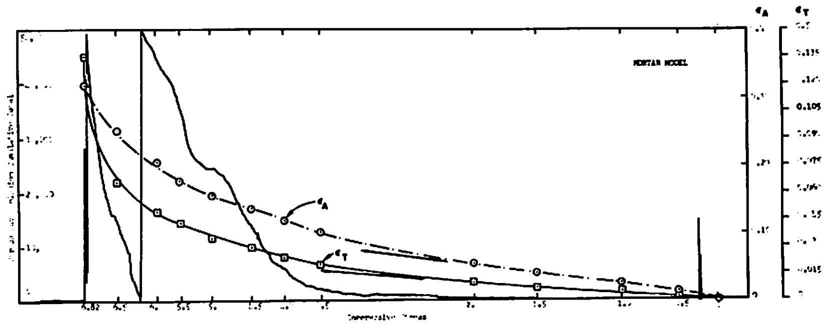

Figure 9 Stress-Wave Data, Axial and Transverse Strain vs Compressive Stress

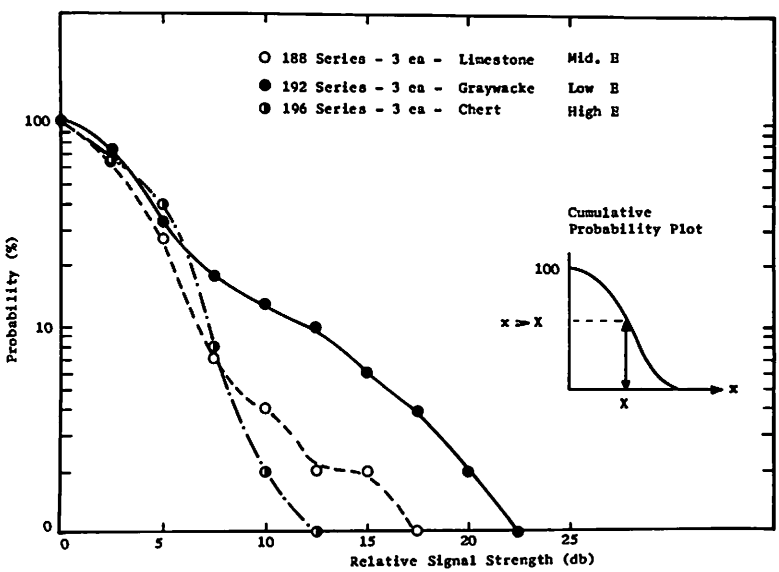

Figure 10 Probability vs Signal Strength, Specimen 196-8, Chert Concrete

DISCUSSION

Q G. J. HILL, U. K.

Can Dr. Harris indicate the sensitivity of the equipment for detecting crack growth ?

A D. O. HARRIS, U. S. A.

It is very difficult to quantitatively state the minimum amount of crackgrowth that can be detected by use of acoustic emission. That depends greatly on the instrumentation system, material, and mechanism of crackgrowth. In my experience, I have found that crackgrowth from a sharp notch in high strength steel containing hydrogen is accompanied by a great deal of acoustic emission. Hundred of thousand of counts are observed before any crack is visual to the unaided eye, so acoustic emission techniques are very sensitive to crackgrowth.

Q R. von KLOT, Germany

Have you done some work at elevated temperatures ?

A D. O. HARRIS, U. S. A.

No, we haven't. All our work has been done at room temperature and below.

Q R. W. DERBY, U. S. A.

1. Was that slide a picture of the little vessel at Oak Ridge ? Can you tell us what happened ? (The work was done in another part of our laboratory).
2. What effect would temperature have on emission ? What would be the difference between NDT and NDT+60 ?

A D. O. HARRIS, U. S. A.

1. Yes, that little vessel was part of an investigation sponsored by Oak Ridge. The test results are described in the paper, and references cited therein.
2. I would expect temperature to have a marked effect on acoustic emission characteristics, especially in materials whose mechanical properties are temperature sensitive. I would expect more emission at NDT, than at NDT+60, because (generally speaking) more emission is observed from more brittle materials.

think that a crack which is growing at constant load is dangerously near to catastrophic failure.

A D. O. HARRIS, U. S. A.

In tests in which a crack is growing under constant load, the acoustic emission comes only from the crack growth. In a cracked specimen under rising-loading conditions, acoustic emission can be observed from the plastic deformation in the highly stressed region near the crack tip - even though the crack is not growing.
A crack growing at constant load (such as from corrosion or the presence of hydrogen) is not necessarily dangerously near to catastrophic failure.

Q A. G. JACOBI, Switzerland

What areas might be covered with one sensor and what distances are realistic for crack-detecting by acoustic emission analysis ? How do you find the basic acoustic frequency band in which you should look for the sounds to detect crack propagation ?

A D. O. HARRIS, U. S. A.

Areas on the order of 20 feet in diameter can be monitored with one stationary acoustic emission sensor. The amplitude of the emission events, and the frequency range in which you are operating affect the size of the area that can be covered.
Acoustic emission events contain frequencies over a very broad range, even up into the tens of megahertz. The range selected is a compromise. We have found the 100-300 kHz range to be a good compromise, and useable for a wide variety of applications.

Q J. KADLEC, Germany

Can you tell us something about the spectral composition of your signals ?

A D. O. HARRIS, U. S. A.

Our instrumentation is not able to measure the frequency content of the acoustic emission signals. However, other investigations, both theoretical and experimental, indicate that the frequency spectrum of an acoustic emission event covers a very wide range; something like DC to 50 MHz.

Q W. H. IRVINE, Canada

On the fourth page cumulative emission $\Sigma N = AK^n$. However from LEFM plastic zone size is proportional to 1/(yield stress). However you say on the next page that increase in your irradiated metal is due to increase in yield stress. This seems inconsistent. Can you

A D. O. HARRIS, U. S. A.

The amount of emission per unit volume of plastically deformed material increases markedly with increasing yield stress. Evidently, this increase per unit volume more than offsets the decrease in the plastic zone size due to the increased yield stress. Other factors, such as the amount of subcritical crack growth prior to final fast fracture, also play an important role.