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MONITORING HIGH TEMPERATURE FATIGUE
USING ACOUSTIC EMISSION TECHNIQUES

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ABSTRACT

This paper presents a unique method for detecting the onset and progress of fatigue damage at elevated temperatures. The technique utilizes acoustic emission information which can now be measured in a high temperature environment.

Acoustic emission profiles of the fatigue process in metals show distinct and reproducible features which can be related to microcracking and the nucleation of a macrocrack. These results have been observed with a variety of metals in environments ranging from room temperature to 1200°F. Application of this detection method is still in the developmental stages so documented data is limited at this time.

(a) This paper is based on work performed under United States Atomic Energy Commission Contract AT(45-1)-1830.

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INTRODUCTION

Early and consistent detection of the onset of fatigue damage and assessment of fatigue crack growth is difficult under the best of conditions. An elevated temperature environment further aggravates the problem.

A new nondestructive surveillance technique which promises to alleviate this problem is now available. The technique consists of detection and analysis of "acoustic emission".

Basic study of the acoustic emission phenomenon started in the late 1950's in the United States and Germany.⁽¹⁻³⁾ Development of the potential of acoustic emission for high resolution, nondestructive surveillance of structures and pressure systems to detect growing flaws, began in the early 1960's.

Battelle-Northwest has carried on an active research and development program in the area of acoustic emission since early 1966. A major effort has been to apply acoustic emission as a

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reliable continuous integrity monitor for the primary pressure boundaries of nuclear power reactors.⁽⁴⁾ In addition, work has been done in investigation of acoustic emission related to formation of cracks in welds,⁽⁵⁾ metal fatigue, studying fracture modes in pressure vessels,⁽⁶⁾ and fracture in graphite and ceramics.⁽⁷⁾

Acoustic emission arises from energy released as a solid material undergoes plastic deformation and fracture. Part of this energy is converted to elastic waves which propagate through the material and can be detected at the material surface using high sensitivity sensors. Unique features of acoustic emission as a flaw detection method are the ability to detect crack formation or growth at the time it occurs and to accomplish this remotely. Also, simultaneous interrogation of multiple sensors provides the necessary information to locate the source of the signals (the flaw).

There are two common misunderstandings concerning acoustic emission. It is a strictly passive technique; no energy is introduced to the device being monitored as is done in ultrasonic examination. Secondly, the method will not detect static flaws; deformation or cracking must be in process to provide energy for acoustic emission generation.

Current or potential applications of this new surveillance technique include:

- Detection of incipient fatigue failure in ground vehicles and aircraft
- Monitoring of pressure vessels during hydrotesting to detect and locate flaws

- Monitoring of weldments for cracking during cooling
- Continuous surveillance of nuclear reactor primary pressure boundaries to detect and locate active flaws.

DETECTION OF FATIGUE DAMAGE AT HIGH TEMPERATURE

This paper presents a unique method for detecting the onset and progress of fatigue damage at both room temperature and elevated temperatures and evidence supporting the validity of the method. The technique is still in the developmental stage for this application, hence documented data is limited.

Figure 1 is a block diagram of a basic acoustic emission detection and analysis system. The general requirements for such a system are high sensitivity detectors, low noise signal amplification ($\sim 5 \mu\text{V}$ noise referred to input at the preamplifier), sharp cut-off filters (35 to 50 dB/octave) to attenuate unwanted environmental noise, and a method for analyzing the acoustic emission information to provide signal rate, energy, summation and source location. This system provides a strip chart readout of emission signal rate, energy, and summation. Source location parameters are printed out on a digital printer. A more sophisticated system is now in operation which uses a minicomputer for all of the data processing.

One special requirement for applying this technique to high temperature fatigue monitoring is that of a suitable sensor. Piezoelectric crystals with adequate sensitivity for detecting acoustic emission are generally limited to a service temperature

of less than 500°F. Lithium niobate is one notable exception, but even with it there remains the problem of acoustic coupling to the monitored surface at high temperature. A solution to this problem is a metal wave guide, shown in Figure 2.

Metal wave guides can be coupled by metallurgical bonding or pressure coupling to the monitored surface. With proper design, the wave guide can be made virtually any length necessary to reach a sufficiently cool environment to permit signal sensing with a piezoelectric crystal attached to the outer end of the wave guide. From this point on, a conventional acoustic emission monitor system is used.

The outstanding features of detecting fatigue damage by acoustic emission are early detection of an identifiable and universal step in the fatigue sequence (macrocrack nucleation), capability to detect crack growth, and capability to locate the flaw site using emission information.

Figure 3 summarizes acoustic emission from low cycle tension-compression fatigue testing of a high nickel alloy at 1000°F. Three separate areas of emission activity are evident prior to failure. The first is characteristic of emission from initial mobile dislocation pinning (the Kaiser effect) and the second is attributed to initiation of microcracking. The third is definitely due to macrocrack formation. Some of the fatigue tests were terminated in the vicinity of the third peak and the specimen pulled in tension. Percent of fatigue fracture area ranged from 3 to 30% as indicated by heat etched areas of the fracture surface.

In another set of tests, center notch panel specimens of 0.030 in. thick aluminum were fatigued in high cycle, tension-tension. Formation of a macrocrack is again clearly indicated by acoustic emission prior to becoming visible (Figure 4).

Subsequent work with notched, Type A-212-B steel, fatigue specimens yielded results which substantiate macrocrack nucleation as the source of the sharp increase in acoustic emission preceding visible crack development. It also provided some further insight to the resolution attainable by acoustic emission.

The specimen shape and loading is shown in Figure 5 along with the acoustic emission response curve generated by the fatigue process. The notched, bar specimen was cycled in tension-tension for a total of 716,000 cycles. The characteristic sharp increase in acoustic emission occurred 11,000 cycles prior to this. Upon examination of the specimen, no surface crack was visible even under a microscope. However, metallographic examination, revealed the conditions shown in Figures 6 and 7. An abundance of microcracking was evident in the vicinity of one corner of the notch. A section 1/8 in. below the surface showed a macrocrack about 0.0025 in. deep by 0.030 in. long in the same corner of the notch. Further examination of the specimen showed only additional microcracks. Nucleation of the macrocrack definitely appears to produce the sharp increase in emission. The gradual increase in emission starting at about 400,00 cycles is attributed to an increasing rate of microcracking. These data indicate that acoustic emission shows a distinct benchmark delineating incipient fatigue failure.

Source location by acoustic emission will not be discussed in detail here, but basically, this utilizes time of signal arrival at multiple sensors to locate signal origin point by seismic triangulation techniques.

SUMMARY

Acoustic emission monitoring offers flaw detection capabilities not available by any other known technique. With the development of the metal wave guide sensor it can now be utilized in a high temperature environment. Emission from fatigue shows characteristics which are particularly definitive of the state of the damage process. The functions which acoustic emission surveillance can perform in high temperature fatigue considerations are to identify a significant point in the fatigue process-macrocrack nucleation, locate the incipient failure point, provide a means of following crack growth, and provide, with suitable calibration, a measure of remaining fatigue life in a given test specimen or component.

For this technique to become a recognized, reliable tool for assessing high temperature fatigue damage, further work needs to be done to substantiate and correlate the indicators with the source in the fatigue process. Potential applications, however, such as enhancing basic material studies in a high temperature fatigue environment, detecting incipient fatigue failure in high temperature functional systems such as nuclear reactors, jet engines, and high pressure steam piping plus similar lower temperature applications amply justify continued development of this method.

REFERENCES

1. Ultrasonic Observation of Twinning in Tin, W. P. Mason, J. H. McSkimin, W. Shockley, Physical Review, Vol. 73, No. 10, May 1948, pp. 1213-1214.
2. Untersuchungen über das Auftreten Geräuschen Beim Zugversuch, J. Kaiser, (Ph.D. Thesis; Techn. Hochschule, München, 1950) and Arkiv Fur das Eisenhüttenwesen, Vol. 24, 1953, pp. 43-45.
3. Acoustic Emission Under Applied Stress, B. H. Schofield, R. A. Bareiss, A. A. Kyrala, Wright Air Development Center (USE) Technical Report 58-194, ASTIA Document No. AD155674, April 30, 1958.
4. Detection of Incipient Failure in Nuclear Reactor Pressure Systems Using Acoustic Emission, P. H. Hutton, AEC Research and Development Report, BNWL-997, April 1969.
5. The Use of Acoustic Emission As A Weld Quality Monitor, W. D. Jolly, BNW-SA-2727, presented at the American Society of Mechanical Engineers 24th Annual Petroleum Engineering Conference, Tulsa, Oklahoma, September 21-25, 1969.
6. Integrity Surveillance of Pressure Systems By Means of Acoustic Emission, P. H. Hutton, BNWL-SA-2194, presented at the International Conference on Pressure Vessel Technology, Delft, Holland, September 29 - October 2, 1969.
7. Acoustic Emission Monitors Crack Growth in Ceramics, D. M. Romrell, BNWL-SA-3064, to be presented at the 1970 Spring Conference of the American Society of Nondestructive Testing, Los Angeles, California, March 10, 1970.

BLOCK DIAGRAM

ACOUSTIC EMISSION MONITOR SYSTEM

Figure 1 - Block Diagram - Acoustic Emission Monitor System

WAVE GUIDE ACOUSTIC
EMISSION SENSOR

Figure 2 - Wave Guide Acoustic
Emission Sensor

Figure 3 - Acoustic Emission Response - Fatigue of High Nickel Steel

Figure 4 - Acoustic Emission From Fatigue Crack Formation In Thin, Center Notched, 2024-T3 Aluminum Panel.

Figure 5 - Acoustic Emission From Carbon Steel Fatigue Specimen

TYPE A-212-B CARBON STEEL FATIGUE SPECIMEN
METALLOGRAPHY SHOWING ACOUSTIC EMISSION SOURCES

Figure 6 - Microcrack Emission Sources-
Carbon Steel Fatigue
Specimen

TYPE A-212-B CARBON STEEL FATIGUE SPECIMEN
METALLOGRAPHY SHOWING ACOUSTIC EMISSION SOURCES

Figure 7 - Macrocrack Emission Source -
Carbon Steel Fatigue
Specimen

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