207214

Characterization Of Longitudinal Splitting And Fiber Breakage In Gr/Ep Using Acoustic Emission Data

Thomas M. Ely
Acoustic Emission Consultants
60 Woodland Drive
Bridgeton, NJ 08302
(609) 451-7531

Eric v. K. Hill
Aerospace Engineering Department
Embry-Riddle Aeronautical University
600 S. Clyde Morris Boulevard
Daytona Beach, FL 32114
(904) 226-6760

Abstract

A composite tensile test specimen was designed such that fiber breakage and longitudinal splitting occurred at a known position in the specimen. By studying the acoustic signature of each failure mechanism distinct characteristics in the data were identified that uniquely related the acoustic emission parameters with either fiber breakage or longitudinal splitting.

Introduction

In the interest of identifying a unique set of AE characteristics associated with a single failure mechanism in composite materials, previous research efforts (Milke, et al, Gaffari and Awerbuch, and Ely) have employed specimens designed to fail via a specific mechanism. Significant attributes of the resulting data were concluded to be characteristics of the failure mechanism under study. The research presented herein has been developed using a similar approach. A tensile test specimen was designed such that a small bundle of isolated fibers would fracture and longitudinal splits would emanate from a known position. Since it was known that the tip of the longitudinal splits would propagate during failure and that the fiber breaks would all occur at one cross-section, event location was used to define data subsets such that the AE characteristics of each failure mechanism could be studied separately.

Testing Procedure

A 15 inch by 1.125 inch, five ply, 0° unidirectional graphite/epoxy specimen was manufactured by means of wet lay-up and is shown in Figure 1. Two cuts were made on one side of the specimen prior to curing. This was done in order to isolate a one sixteenth inch wide bundle of fibers (Figure 2).r

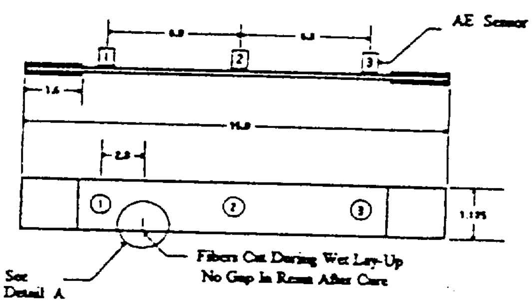

Figure 1. Longitudinal Split/Fiber Break Specimen

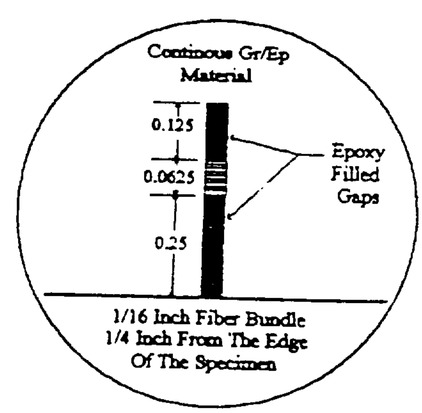

Figure 2. Detail A - Cut Fiber Cross-Section

After curing, the specimen was trimmed to size and the edges polished to achieve the final dimensions. Aluminum tabs (1.5 X 1.125 X 0.050 inches) were bonded to the specimen using the matrix epoxy. Five minute epoxy was then used to bond the three R-15 sensors to the specimen. By breaking leads at a measured distance from each sensor, good acoustic coupling between the sensors and the specimen was verified and the wave speed calculated (the difference in measured distance from the sensors divided by the difference in the recorded arrival time). This procedure was repeated at several different positions between the sensors to ensure the accuracy of the calculated value. Using the wave speed and the sensor positions, a location array was defined in the LOCAN-AT software so that AE event parameters would be part of the output data set. The test data presented herein were collected using the following AE input parameters: Preamp Gain = 40 dB, Gain = 20 dB, Threshold = 40 dB, PDT = 30μs, HDT = 150μs and HLT = 300μs. Location accuracy was checked by breaking leads at one inch from each sensor and at the flaw site. After performing the lead breaks, the specimen was gripped in an MTS machine. Data acquisition and ramp loading (100 pounds per minute) were initiated simultaneously.

Data Analysis

The original flaw site (the cut fibers) was located two inches from AE sensor 1 (Figure 1). Visual examination of the specimen after failure revealed the existence of two longitudinal splits emanating from the flaw site and the fracture of the aforementioned fiber bundle. One split advanced toward sensor 1, terminating one half inch from the cut section. The second split terminated under sensor 2 (three inches from the cut). There were no obvious characteristics in the raw data (1358 events) that could be clearly associated with either longitudinal splits or fiber breaks. However, since the fiber bundle fractured at the cut fiber cross-section and the longitudinal splits also originated at this position, the AE data from that site (Figure 3) were investigated.

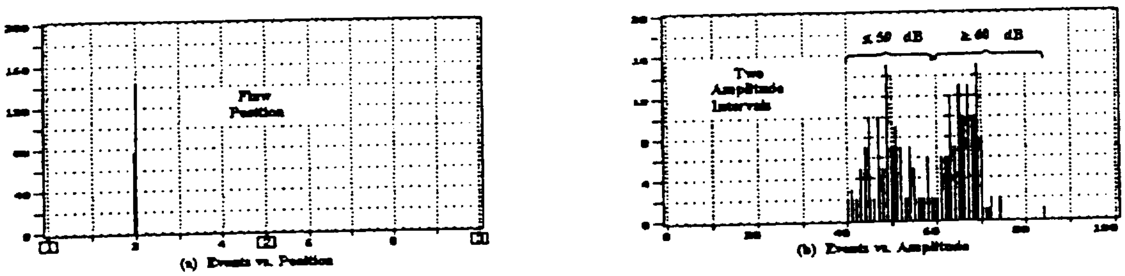

Figure 3. Flaw Site Data (218 Events)

This data set contained two discrete data intervals for amplitude, duration, and counts. Since the amplitude intervals were very distinct (Figure 3), this data set was further subdivided into a set having event amplitudes of 59 dB or less and one having event amplitudes of 60 dB or greater. These two data sets are shown in Figures 4 and 5, respectively. It should be noted that 14 of the 218 events shown in Figure 3 were lost as a result of subdividing the data into these two amplitude bands. The loss was due to the first hit sensor (the event sensor) having an amplitude in the higher band and the second hit sensor having an amplitude in the lower amplitude band.

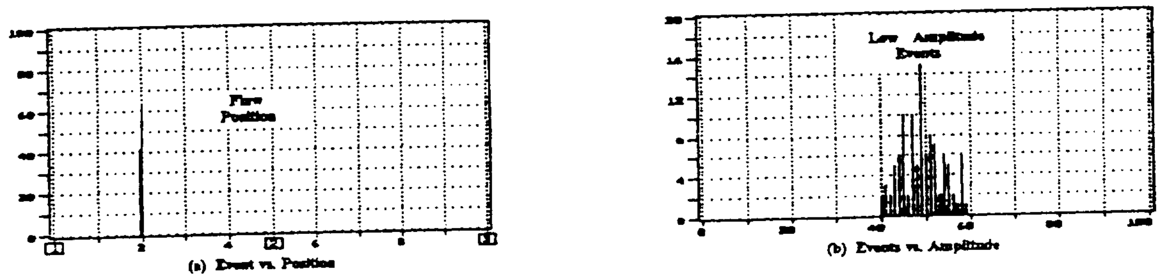

Figure 4. Low Amplitude (≤ 59 dB) Flaw Site Data (104 Events)

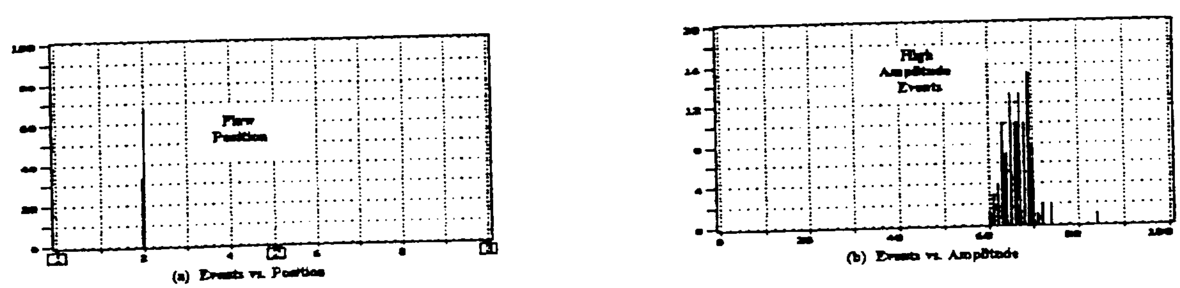

Figure 5. High Amplitude (≥ 60 dB) Flaw Site Data (100 Events)

Upon review of the data it was determined that the majority of the events in both data sets occurred over the same load/time interval. Additionally, the duration, counts and energy characteristics of each of the data subsets indicated that there was almost no overlap in these three AE parameters (Table 1).

Table 1. Unique Event Characteristics

	Event Amplitude ≤ 59 dB (104)	Event Amplitude ≥ 60 dB (100)
Event Load	800 - 900 lbs.	800 - 900 lbs.
Duration	≤ 200 μs	> 200 μs
Counts	< 30	> 30
Energy	≤ 10	> 10

At this point we have two mechanisms (fiber breaks and longitudinal splitting) and two distinct data sets but nothing to indicate which mechanism belongs to which data set. It could be argued that fiber breaks store more mechanical energy than the matrix material; hence, we would expect a fiber break signal to be more energetic. Here the high amplitude signals all had energies above 10 units and the low amplitude signals all had energies less than 10 units (Table 1). We would also expect that there would be a build-up of fiber breaks leading up to final fracture of the bundle (Hoskin and Baker Figure 2.10) which occurred at 1600 seconds. Careful study of the Events vs. Time plot for both data sets revealed that there was essentially no build-up over time for the low amplitude events (Figure 6(a)), whereas there was a build-up for the high amplitude events (Figure 6(b)).

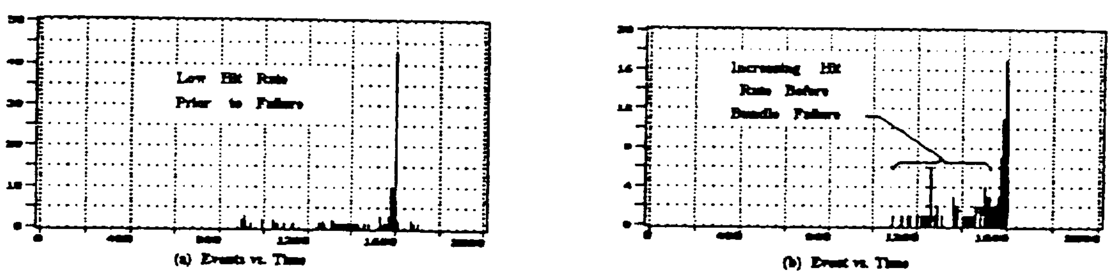

Figure 6. Time Behavior of Amplitude Data (a) Low Amplitude Event Data (b) High Amplitude Event Data.

Most of the low amplitude events that occurred before t = 1600 seconds were probably produced by the aforementioned short split that propagated toward sensor 1. This split propagated slowly throughout the load cycle; on the other hand, the longer split was not apparent until after the fiber bundle fractured. All of the above suggested that the low amplitude, short duration, low counts and energy data were due to longitudinal splitting, while the high amplitude, long duration, high counts and energy data were due to fiber breaks.

Conclusions

The AE data from discrete fiber breakage and longitudinal splitting at known positions were recorded and unambiguously characterized in this work. Using source location as a filter criteria, it was determined that when fiber breaks and longitudinal splitting occur at the same position, the stronger signals (high amplitude/energy/counts and long duration) resulted from fiber breakage and the weaker signals (low amplitude/energy/counts and short duration) resulted from longitudinal splitting.

References

Ely, T. M., Failure Mechanism Characterization in Graphite/Epoxy Using Acoustic Emission Data, (M.S. Thesis, Embry-Riddle Aeronautical University, Daytona Beach, Florida 1993).

Ghaffari, S. and J. Awerbuch, "Monitoring Initiation and Growth of Matrix Splitting in a Unidirectional Graphite/Epoxy Composite", Journal of Acoustic Emission, 1988, No. 1-2, pp. S301 -S305.

Hoskin, B. C. and A. A. Baker, Editors, Composite Materials For Aircraft Structures, (American Institute of Aeronautics and Astronautics, New York, New York), 1986, pp. 22

Milke, W., A. Hampe, O. Hoyer and K. Schumacher, "Analysis of Acoustic Emission Events From Single Fiber Pullout Experiments", Journal of Acoustic Emission, 1990, No. 2, pp. 103-108.