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Detection and Location of Transverse Matrix Cracks in Cross-Ply Gr/Ep Composites Using Acoustic Emission

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Introduction

Transverse matrix cracking in cross-ply gr/ep laminates was studied with advanced acoustic emission (AE) techniques. The primary goal of this research was to measure the load required to initiate the first transverse matrix crack in cross-ply laminates of different thicknesses. Other methods had been previously used for these measurements including penetrant enhanced radiography, optical microscopy, and audible acoustic microphone measurements. The former methods required that the mechanical test be paused for measurements at load intervals. This slowed the test procedure and did not provide the required resolution in load. With acoustic microphones, acoustic signals from cracks could not be clearly differentiated from other noise sources such as grip damage, specimen slippage, or test machine noise. A second goal for this work was to use the high resolution source location accuracy of the advanced acoustic emission techniques to determine whether the crack initiation site was at the specimen edge or in the interior of the specimen.

Significant research efforts [1 and references contained therein] have been spent on attempts to differentiate damage mechanisms in composites using conventional, parameter based, AE measurements. The majority of this work has focused on analysis of AE signal amplitude distributions. The theory is that different source mechanisms, such as matrix cracking, fiber breakage, and delamination, should generate different amplitude signals. However, the claims as to which source mechanism generates which amplitude signal have been conflicting. Few results have been confirmed by direct observations of damage mechanisms that created a particular signal. Also, the effects of the large attenuation, common in these materials, on the measured signal amplitude, has been neglected in these measurements and analyses.

Two recent studies of transverse matrix cracking in cross-ply composites, however, have yielded good results. In both cases, the cracks detected by AE were confirmed with other techniques including radiography, microscopy, and ultrasonics. In the first study [1, 2], conventional AE amplitude measurements were correlated with cracks in cross-ply laminates with different numbers of 90 degree plies. For specimens with more than two 90 degree plies in a layer, there was excellent correlation (near 1-1) between large amplitude signals and observed cracks. Furthermore, there was good separation in amplitude between the peak in large amplitude signals and the peak containing numerous smaller amplitude events. For specimens with only one or two 90 degree plies, the correlation was not nearly as good and distinct peaks in the amplitude distributions did not exist. These results were not well understood, but can be explained by the findings of this study.

In the second study [3, 4], broad band sensors and a digital oscilloscope for waveform acquisition were used in addition to conventional (parameter based) AE measurements. Analysis based on wave propagation models in plate geometries allowed discrimination of signals generated by cracks from extraneous noise. Transverse matrix cracks were shown to preferentially generate extensional plate mode signals due to their in-plane source motion. Extraneous noise sources such as grip damage generated signals with large flexural mode components. Waveform capture rate limitations prevented digital acquisition of all signals during the tests. However, with the conventional system optimized for detection and location of crack induced extensional mode signals, fair correlation between AE determined crack locations and cracks measured with an ultrasonic backscatter technique was obtained.

In this research, advanced AE techniques using broad band sensors, high capture rate digital waveform acquisition, and plate wave propagation based analysis were applied to cross-ply composite coupons with different numbers of 0 and 90 degree plies. Noise signals, believed to be caused by grip damage or specimen slipping, were eliminated based on their plate wave characteristics. Such signals were always located outside the sensor gage length in the gripped region of the specimen. Cracks were confirmed post-test by microscopic analysis of a polished specimen edge, backscatter ultrasonic scans, and in limited cases, by penetrant enhanced radiography. For specimens with three or more 90 degree plies together, there was an exact 1-1 correlation between AE crack signals and observed cracks. The ultrasonic scans and some destructive sectioning analysis showed that the cracks extended across the full width of the specimen. Furthermore, the locations of the cracks from the AE data were in excellent agreement with the locations measured with the microscope. The high resolution source location capability of this technique, combined with an array of sensors, was able to determine that the cracks initiated at the specimen edges, rather than in the interior.

For specimens with only one or two 90 degree plies, the crack-like signals were significantly smaller in amplitude and there was not a 1-1 correlation to observed cracks. This was similar to previous results [1, 2]. In this case, however, ultrasonic and destructive sectioning analysis revealed that the cracks did not extend across the specimen. They initiated at the edge, but did not propagate any appreciable distance into the specimen. This explains the much smaller AE signal amplitudes and the difficulty in correlating these signals to actual cracks in this, as well as in the previous study [1, 2].

Experiment

Tensile coupon specimens (2.54 cm. wide by 27.94 cm. long) of AS4/3502 were tested under stroke control loading (0.127 mm/minute). Because grip damage noise could be eliminated by waveform analysis, grip tabs were unnecessary. Six different cross-ply laminates were tested. The stacking sequences were $[0_n, 90_n, 0_n]$ where n ranged from one to six. Thus, the samples varied in thickness from 3 to 18 plies. Rather than a single sensor at either end of the specimen, four broadband sensors (Digital Wave B1000) were used. At either end of the specimen gage length, a pair of sensors were positioned. The outer edge of each 6.35 mm diameter sensor was aligned with the edge of the specimen. The motivation for this sensor array arrangement was the determination of the initiation site of the crack. Not only could the linear location along the length of the specimen be determined, but lateral location information was also obtained.

The signals were amplified 20 dB by wide band preamps (Digital Wave PA2400G) and then input into a digital acoustic emission analysis system (Digital Wave F4000). Additional system gain was applied, depending on the specimen thickness. Thicker specimens generated signals of larger amplitude. The additional system gain ranged from as little as 6 dB for the thickest specimen to 18 dB for the nine ply specimen ($n=3$). For the three and six ply laminates, the gain was significantly increased with the preamp gain increased to 40 dB and the system gain set as high as 18 dB in attempts to capture the much smaller amplitude signals from the partial cracks not propagating across the specimen. The maximum digitization sampling frequency of 25 MHz was used to provide the most accurate location results. Location was performed, post-test, using manual, cursor based, arrival time determination. The load at which a given crack signal was detected was obtained from a parametric measurement system in the AE

instrument.

Results and Discussion

For the laminates with $n = 3$ or larger, there was a 1-1 correlation between crack signals detected and observed cracks. A few extraneous noise signals which located outside the sensor gage length and were believed to be caused by grip damage or specimen slippage, were detected in some tests. These were eliminated based on plate waveform analysis. Figure 1 shows typical waveforms from a crack signal

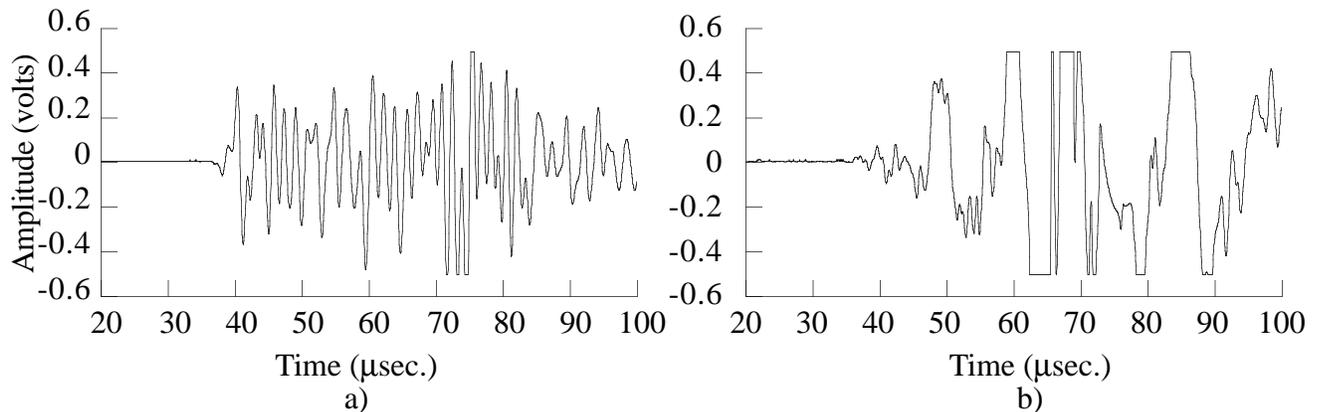


Figure 1 Typical signals caused by a) transverse matrix crack and b) grip slippage or damage

which contains high frequency extensional mode components, and a low frequency flexural mode noise signal. Excellent crack location accuracy, as compared to microscopy measurements, was obtained from the AE data. The average of the absolute value of the difference in crack locations from AE and microscopy was 3.2 mm for a nominal sensor gage length of 152 mm. The amplitude of the signals was proportional to the thickness of the specimen, with larger numbers of 90 degree plies through which the crack propagated producing larger amplitude signals. The following table shows values for loads for first transverse matrix crack initiation versus laminate stacking sequence for one set of specimens.

Stacking Sequence	Load for first crack (lbs.)
$[0_6, 90_6, 0_6]$	5688
$[0_5, 90_5, 0_5]$	4153
$[0_4, 90_4, 0_4]$	3594
$[0_3, 90_3, 0_3]$	3220

For the thin laminates ($n = 1$ or 2), the cracks were not always successfully detected. Ultrasonic backscatter scans and destructive sectioning microscopy analysis showed that the cracks, which were visible at the specimen edge, did not extend into the interior of the specimen. This difference in crack initiation and growth explains the much smaller amplitude signals and the difficulty in detecting these cracks.

References

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