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Research Article

A Study on the Failure Mechanisms of Composite Laminates using Acoustic Emission Monitoring

Alireza Daneshmehr[a], Alireza Asa[a*] and Saeid Abazary[b]

[a]Department of Mechanical Engineering, College University, Tehran, Iran.
[b]Department of Mechanical Engineering, Science and Research Branch, Islamic Azad University, Kermanshah,

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Abstract

Delamination and Fracture are the most common failure mode in composite materials, since they will result in the reduction of stiffness and can grow throughout other layers. Buckling is consisted of two main stages including delamination and fracture. The complex failure mechanisms that are commonly considered as the distinctive characteristic of composites are being amenable to nondestructive test advance. This research adopts the acoustic emission technique to study the failure mechanisms and damage evolution of glass/polyester composite laminatesunder buckling loading has been carried out. The tested of glass/polyester composite specimens include two lay-up patterns: $[45^0/-45^0]_{6s}$ *and* $[0^0]_{6s}$*.Each specimen includes 12 layers whit ruck in surface , and the thickness of each layer is about 0.416 mm. Moreover,the microscopic properties of different composite specimens after fracture are watched and analyzed by scanning electron microscope (SEM).Based on the SEM conception, the controlling microscopic failure mechanisms of composites including the splitting matrix cracking, fiber/matrix interface debonding, fiber pull-out and breakage as well as delamination are identified.*

Keywords: *Acoustic Emission, Buckling, Failure Mechanisms.*

1. Introduction

Glass fiber polymer composites have been increasingly use in areas, and wind-power electricity generation because of their advantages such as high strength and stiffness to weight ratios.

If intralaminar cracking for some layer appears, other layers may not be much effected because of the delamination. Thus, the damage and failure properties between two neighboring separated layers keep independent (B.N. Cox, Q.D.Yang, 2006; P.F.Liu, J.Y.Zheng, 2010).

However, the laminated properties of composites also bring about some negative influence that may restrict the application of composites. An important factor lies in the complex failure mechanisms: intralaminar and intralaminar failure as well as their interactions. Intralaminar failure includes the matrix cracking, the fiber/matrix debonding, and the fiber pull-out and breakage (P.F.Liu, J.Y. Zheng, 2008; P.F.Liu, S.J.Hou, J.K.Chu, X.Y.Hu, C.L. Zhou,J.Y.Zheng, et al, 2011).

Research on the acoustic response law of composites is worthwhile to further insight into the failure mechanisms and damage evolution of composites. Williams and Lee (J.H. JrWilliams, S.S Lee, 1978), early introduced the acoustic emission to monitor the failure of composites (P.J.de Groot, P.A.M. Wijnen, R.B.F, 1995; Y.H.Yu, J.H. Choi, J.H.Kweon, D.H.Kim, 2006).

Preformed the failure detection of composites by determining the real-time acoustic frequency.explored the failure process for the single-edge-notched laminated composites by studying the high-amplitude acoustic emission events (S.C. Woo, N.S.Choi, 2007). proved it possible to correlate the acoustic emission features such as the number of events, the amplitude and energy to the physical properties (T.Czigany, 2006). Recently, gave a literature review on the application of acoustic emission for the natural fiber composites including the damage evolution and failure mechanisms detection (L. M.De Rosa, C.Santulli, F. Sarasini, 2009).

2.Experimental Test

2.1.Material Specimens

The tested glass/polyester composite specimens include twolay-up patterns: $[45^0/-45^0]_{6s}$ and $[0^0]_{6s}$ and. The properties ofthe polyester resin as a matrix material is density of 1020-1040 kg/m^3. The laminates were prepared by hand lay-up. To prevent slip during loading, end tabs in 20mm x 30 mm length were glued at the same ends of specimens.

* Alireza Daneshmehr is working as Assistant Professor and Alireza Asa is a MSc student in Colleg University, Tehran, Iran,

The composites specimens are shown in Figure 1, Alsodimension and lay-up of 2 specimens are listed in Table 1,Each specimen includes 12 layers, and the thickness of each layer is about 0.416 mm.

Table1 Sizes and lay-up patterns for 2 specimens.

Number	l×w×t (mm)	lay-up patterns
1	220×20×5	$[0]_{6s}$
2	220×20×5	$[45/-45]_{6s}$

2.2 AE Equipment

Acoustic emission software AEWin and a data acquisition system (PAC) PCI-2 with a maximum sampling rate of 40 MHz were used to record AE events. A broadband, resonant type, single-crystal piezoelectric transducer from physical Acoustic Corporation (PAC), called PICO, was used as the AE sensor. The sensor had a resonance frequency of 513.28 kHz and an optimum operating range of 100-750 kHz. The surface of the sensor was covered with grease to provide good acoustic coupling between the specimen and the sensor. The signal was detected by the sensor and enhanced by a 2/4/6-AST pre-amplifier. The gain selector of the preamplifier was set to 40 dB. The test sampling rate was 1 MHz with 16 bits of resolution between 10 and 100 dB. Prior to the damage check, the data acquisition system was calibrated for each kind of specimen, according to a pencil lead break procedure. A repeatable acoustic wave then generated a lead breakage inthe specimen on its surface. At the same time, the velocity and attenuation of the AE waves measured. The lead breakage operation was repeated several times and the sensors. After the calibration step, AE signals were captured during mechanical testing. Signal descriptors, such as amplitude, duration, rise time, counts, and energy, were calculated by the AE software (AEWin) (G. MLiu, 2006).

The tests were carried out in a universal test machine with the load cell capacity of 50000 N at the cross head speed of 5 mm/min.

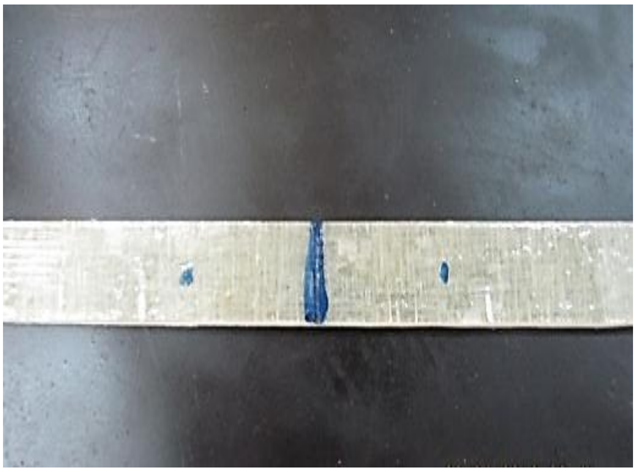


Fig. 1 Tested composite specimens

3. Result And Discussion

Acoustic Emission Representation for Composite Specimen_1

Figure 3, shows the acoustic emission response about the evolvement of energy and amplitudes for the $[0^0]_{6s}$specimen.Figure 4 (a), shows the microstructure of the $[0^0]_{6s}$ specimen after fracture by SEM.

The damage evolution includes three stages: (1) At the early stage (0-15s), the energy, the number and amplitude of acoustic emission signals are small, corresponding to a roughly linear deformation behavior.

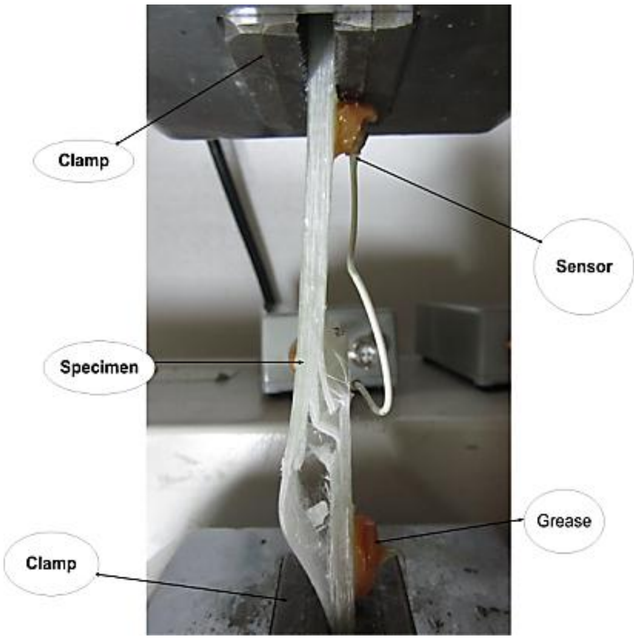


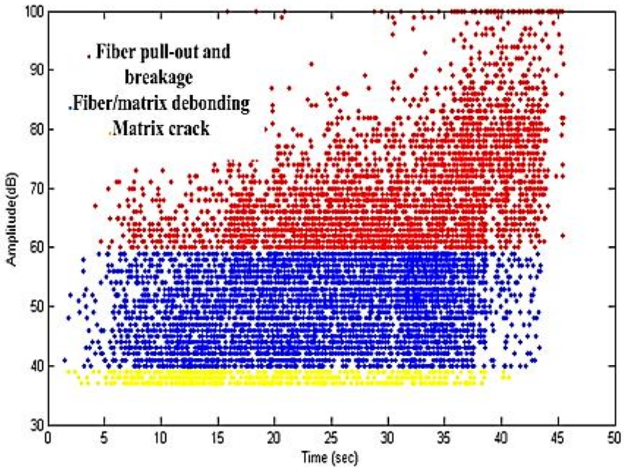
Fig. 2, Composite specimen positioned for acoustic emission test.

The mechanical properties of composites are stable because of few signals. The longitudinal matrix cracks with the 30-40 dB amplitudes other than fiber breakage first appear. As the tensile stress increases, some longitudinal and transverse fiber/matrix interface crack with 40-60 dB amplitudes also spring up. The main failure is still in the forms of the matrix cracking, the interface failure, and little longitudinal fiber breakage with about 60-70 dB amplitude.(2) At the middle damage stage (15-35s), the amplitude range of signals increases, and the high-amplitude signals especially those beyond 80 dB increase remarkably, and the energy slightly increases, marking more failure points and more severe damage areas.

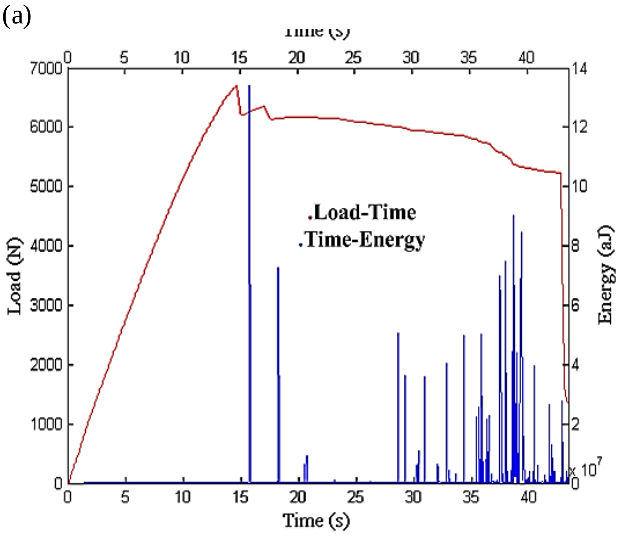
The energy reaches about 10attoJoul (aJ) the Load-time-energy curve shows a small fluctuation due to the fracture localization (Y.H.Yu, J.H. Choi, J.H.Kweon, D.H.Kim, 2006). (3) At the stage of fracture (35-45s), the amplitudes of signals keep the same, but the energy increases remarkably and the number adds continually, represented by more longitudinal fiber breakage with the

60-80 dB amplitudes. The low interlaminar shear strength and transverse fibers have small effects on the longitudinal tensile properties, which are yet determined by longitudinal fibers.

Thus, the high-amplitude signals beyond 80 dB representing the longitudinal fiber breakage are also mixed with the middle and low-amplitude signals showing the progressive matrix cracking and interface failure.



(a)



(b)

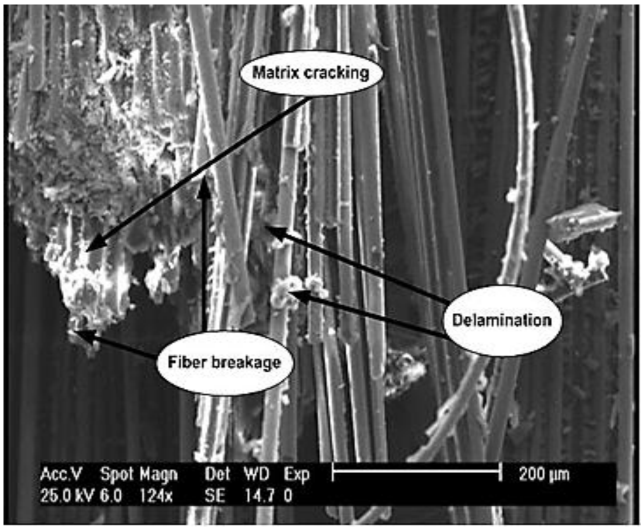
Fig. 3, Acoustic emission response for composite specimen-1: (a) time-amplitude curve and (b) Load-time-energy curve.

4. Acoustic Emission Representation for Composite Specimen_2

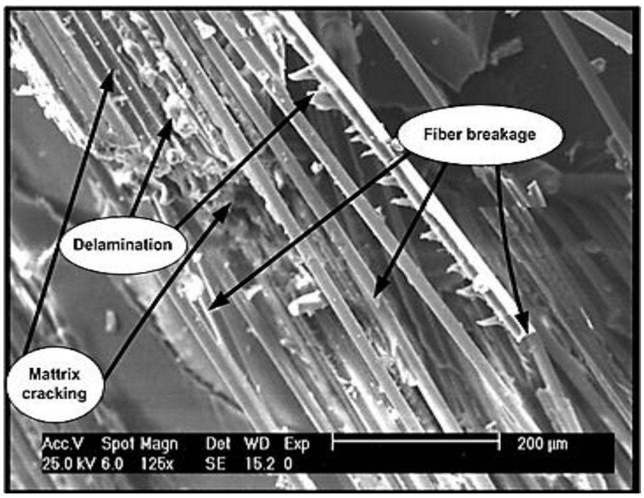
Figure 5, shows the acoustic emission response about the evolvement of energy and amplitude. Figure 4, (b)shows the microstructure of the $[+45^0/-45^0]_{6s}$specimen after fracture by SEM.

In general, the high-amplitude signals for the $[45^0/-45^0]_{6s}$specimen are fewer than those for the $[0^0]_{6s}$ specimen, In contrast with the specimen-1, the energy reaches just about 10attoJoul (aJ) at 35 s and shows more fluctuation for the specimen-2. The damage evolution includes also three stage: (1) at the early stage (0-40s) , the energy number and amplitude of acoustic emission signals are small, corresponding to the elastic deformation. The longitudinal matrix cracks with the 30-40 dB amplitude other than fiber breakage first appear.

Some longitudinal and transverse fiber/matrix interface cracks with 40-60 dB amplitudes also spring up. (2) At the middle stage (40-55s), the amplitude range of signals increases, the energy reaches about $2.5*10^8$attoJoul (aJ) the Load-time-energy curve shows a small fluctuation due to the fracture localization (Y.H.Yu, J.H. Choi, J.H.Kweon, D.H.Kim, 2006) .The main failure is still in theforms if the matrix cracking, the interface failure, and little fiber breakage with about 70 dB amplitude. (3) At the stage of fracture (55-70s), the amplitude of signals keep the same, but the energy increases and the number adds continually, represented by more fiber breakage with the70-80dB amplitudes.



(a)



(b)

Fig. 4,(a)Microstructure of composite spesimen-1 after fracture by scanning electron microscope. (b)Microstructure of composite spesimen-2 after fracture by scanning electron microscope

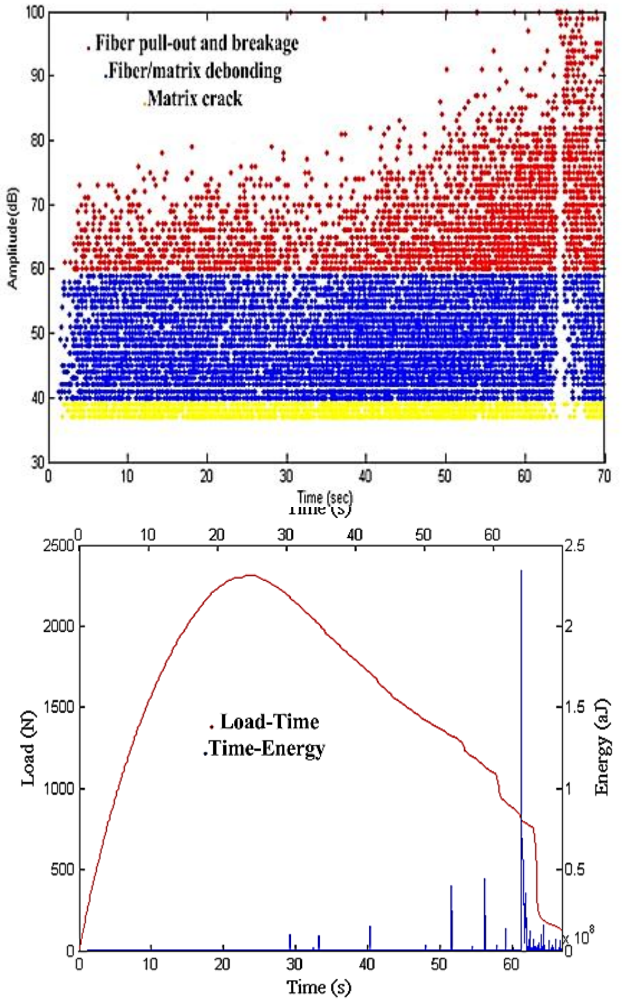


Fig. 5, Acoustic emission response for composite specimen-2: (a) time-amplitude curve and (b) Load-time-energy curve.

Conclusions

This research focuses on the failure mechanisms and damage evolution of glass/polyester composite laminates by combining the buckling experiments and acoustic emission tests.

Effect of two lay-up patterns: energy, amplitude are explored. The real-time acoustic emission response is analyzed from the view of composite micromechanics. From the analysis, the following conclusions are obtained: Although the controlling failure modes can beidentified, the complete separation of all appearing failure mechanisms is not easily realized because of the complex interactions among them. Here, we summarize the amplitude range for each failure mode. The amplitude of the matrix cracking, fiber/matrix interface debonding, delamination, and fiber pull-out and breakage are about 40-60 dB, 50-70 dB, 60-80 dB and 80-100 dB, respectively. However, the amplitude range varies from different composites, sizes and lay-up patterns even for the same failure mode.

It was shown that using continuous AE monitoring during buckle loading of various composites specimen, and then analyzing the captured AE events, it is feasible to reveal the damage mechanisms generated into the material stricter under loading and to follow their evolution in time (damage accumulation).

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