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Research Article

Acoustic Emission For Damage Monitoring of Glass /Polyester Composites under Buckling Loading

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Abstract

Activation of different damage mechanisms during each stage of loading is one of the distinctive characteristics of composite materials which are not unavoidable. In this paper, Acoustic Emission (AE) technique as a non-destructive testing method is developed to detect damage mechanisms in each stage of buckling loading of glass/polyester composite materials. Four types of specimen at different layups, $[0^0,90^0]_{6s}$, $[45^0/-45^0]_{6s}$, $[0^0]_{6s}$ and $[woven]_{6s}$ leading to different level of damage evolution, were studied. During buckling loading, data from mechanical testing and acoustic emission is obtained and its features are analyzed in time-domain. Among the extracted features, count, energy and amplitude variations were more distinctive to show the evolution of damage mechanisms. In this way, the fractured surface of each specimen is prepared and analyzed by SEM to find the type of damages that are existed during loading. SEM observations show that the damage mechanisms including matrix cracking, fiber breakage, debonding and fiber pull-out. This observations are in relation with the results are obtained from AE. The results show that there is a good relation between what AE features variations have proposed and what SEM observations during testing. Also, the efficiency of AE as a useful tool for damage evolution and monitoring is concluded.

Keywords: *Acoustic Emission, Buckling, Damage Mechanisms, SEM.*

1. Introduction

Acoustic emission is a suitable technique for the detection of a wide range of micro-structural failures in different materials. When a failure mechanism is activated, part of the total strain energy is dissipated as a wave that propagates from the failure source through the medium. In polymer-matrix composite three different intra-ply failure modes can be identified, viz. fiber breakage, matrix cracking and fiber matrix debonding. first prompted the possibility of correlating a specific failure mechanism with its acoustic signature (Mehan and Mullin, 1971). In their work they highlighted the relevance of frequency spectral analysis in order to reconstruct the whole failure process. However, very little has been done to correlate the observed signal with a well-defined sound source resulting from a specific failure mode. The major dificulty in establishing a relationship between aspecific failure mode and its acoustic signature is the concurrent observation of different modes. The study of failure by means of acoustic emission has been performed either in complex structures (lami-nates) or in model composites containing only few fibers. investigated the AE signals in a model composite containing single or two fibers (glass, carbon and aramid fibers) in epoxy matrix (Narisawa and Oba, 1984; Narisawa and Oba, 1985). The acoustic signal acquisitions have been carried out by using home-made wide-band acoustic transducers. Acoustic signals were filtered by using a threshold cri-terion. A one-to-one correlation between the number of acoustic signals and the fiber breakage detected with apolarizing microscope has been established. A time-domain analysis revealed that matrix cracking, in allcases, produces lower amplitude signals than fiber breakage. The relationship between amplitudes and rupture mechanisms in more complex composite struc-tures has been investigated (Berthelot, 1988). Laminates of epoxy matrix with carbon fibers have been made byusing pre-pregs. Even if a clear separation of the various damage sources cannot be performed in this case, the fiber breakage mode showed the highest amplitude. The basic principle of acoustic emission technique is to convert the mechanical vibrations in to the electrical signals, and to analyse the acoustic response in terms of the evolvement of the energy, count,peak frequency and amplitude. Research on the acoustic response law of composites is worthwhile to further insight into the failure mechanisms and damage evolution of composites (Yu, Choi et al., 2006) .

In this research, the acoustic emission tests are performed for the glass/polyester composite laminates with different lay-up arrangements. Some representative

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features such as the energy, count and amplitude examine the frequency distribution are extracted with the buckling load to study the controlling failure mechanisms of composites. By test and analysis, the mapping laws for different specimens are obtained, which provides helpful references to unveil the progressive failure properties of composite.

2.Experimental Details

2.1Material and Specimens Preparation

The tested glass/polyester composite specimens include four lay-up patterns: $[0^0/90^0]_{6s}$, $[45^0/-45^0]_{6s}$, $[0^0]_{6s}$ and $[Woven]_{6s}$.

The woven fabric and unidirectional fibers materials are as follows: density of 195 g/m^2, tensile strength warp: 386 n/cm weft: 486 n/cm, thickness 0.28 mm and weave is plain. The properties of the 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 20 mm x 30 mm length were glued at the same ends of specimens.

Also dimension lay-up of 4 specimens is listed in Table 1, each specimen includes 12 layers, and the thickness of each layer is about 0.416 mm.

Table. 1, dimension and lay-up patterns for 4 specimens

Number	l×w×t (mm)	lay-up patterns
1	220×20×5	$[0^0/90^0]_{6s}$
2	220×20×5	$[0^0]_{6s}$
3	220×20×5	$[45^0/-45^0]_{6s}$
4	220×20×5	$[Woven]_{6s}$

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 in the 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) (Liu, Chu et al., 2012) .

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

3.Result and Discussion

3.1Acoustic Emission Representation for Composite Specimen_2

Figure 2, shows the acoustic emission response about the evolvement of energy, count and amplitudes for the [00]6s specimen.

The damage evolution includes three stages: (1) at the early stage (0-24 s), the energy, the number and amplitude of acoustic emission signals are small, corresponding to a roughly linear deformation behavior.

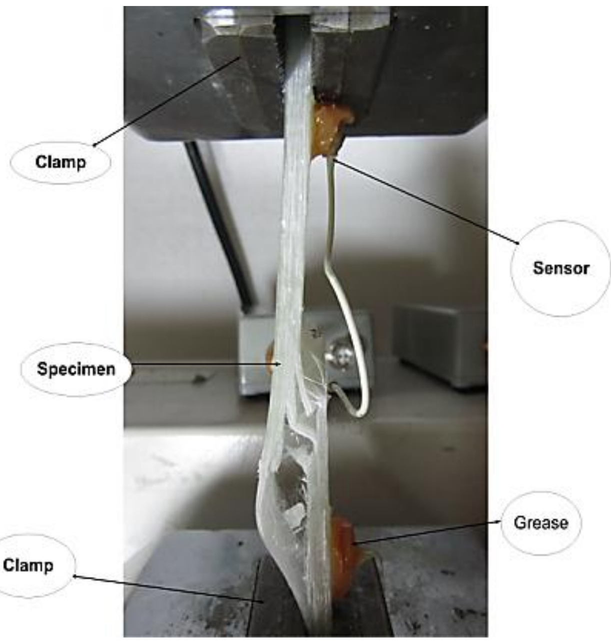
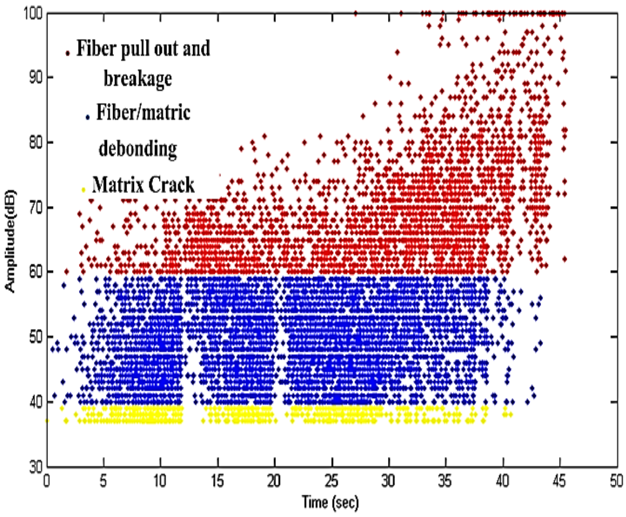


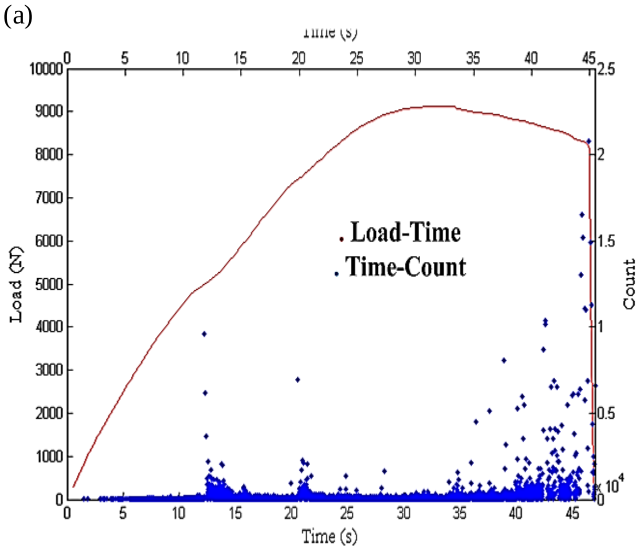
Fig. 1 Composite specimen positioned for acoustic emission test.

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 (Abazary and Oskouei, 2012). 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. This speeds up the no uniform redistributions and variation of stresses as well as the progressive failure of neighboring matrix and interface. At the same time, the transverse 90^0 fibers shear some redistributed stress due to the interlaminar shear, which prevents the damage evolution of 0^0 longitudinal fibers. However, this also results in the progressive transverse failure and delamination and buckling. (2) At the middle damage stage (24-35s), 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.

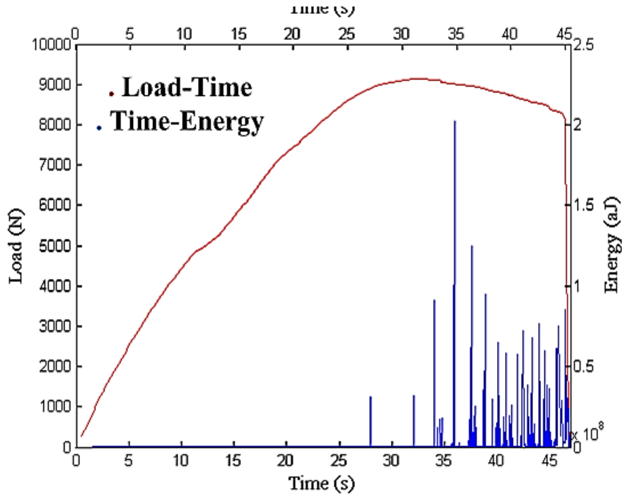
The energy reaches about $2*10^8$ atto Joule (aJ) and the event count reaches about 25 at 35 s though the Load-time-energy curve shows a small fluctuation due to the fracture localization (Yu, Choi et al., 2006) . (3) At the stage of fracture (35-45s), the amplitudes of signals keep the same, but the energy increases remarkably and the number adds continually, represented by more longitudinal fiber breakage with the 60-80 dB amplitudes.



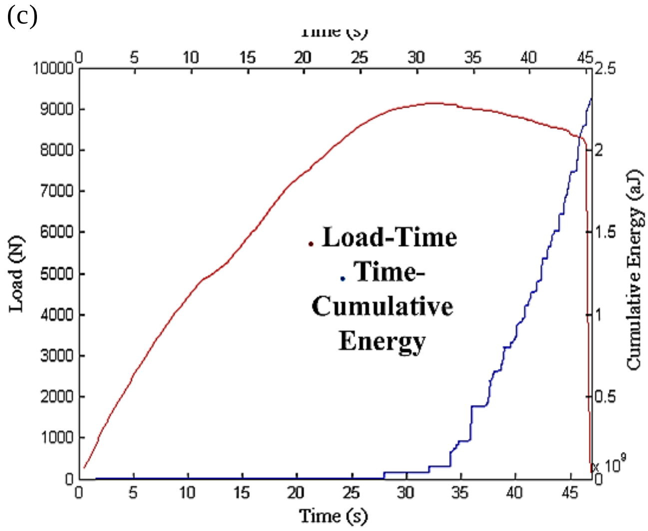
(a)



(b)



(c)



(d)

Fig. 2, Acoustic emission response for composite specimen-2: (a) time-amplitude curve, (b) Load-time-count curve (c) Load-time-energy curve, and (d) Load-time-cumulative energy curve at the moment of fracture.

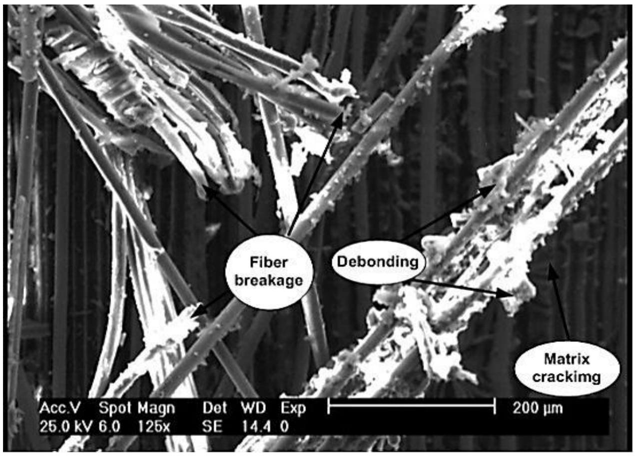
3.2Acoustic Emission Representation for Composite Specimen_3

Figure 4, shows the acoustic emission response about the evolvement of energy, count and amplitude. 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-2, the energy reaches just about $2*10^8$ atto Joule (aJ) at 35 s and shows more fluctuation for the specimen-3, The damage evolution in cludes also three stage: (1) at the early stage (0-45s) , 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.

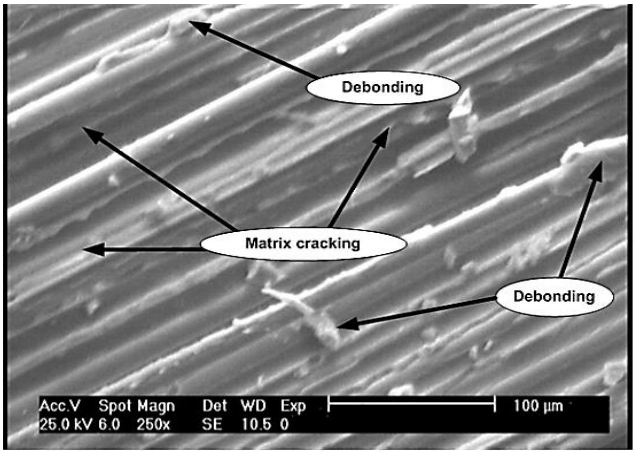
Some longitudinal and transverse fiber/matrix interface cracks with 40-60 dB amplitudes also spring up. (2) At the middle stage (45-55s), the amplitude range of signals increases, the energy reaches about $4*10^9$ atto Joule (aJ) and the event count reaches about 25 at 36 s though the force-time-energy curve shows a small fluctuation due to the fracture localization (Yu, Choi et al., 2006). The main failure is still in the forms if the matrix cracking, the interface failure and little fiber breakage with about 70 dB amplitude. (3) At the stage of fracture (55-65s), the amplitude of signals keep the same, but the energy increases and the number adds continually, represented by more fiber breakage with the70-80 dB amplitudes (Abazary and Oskouei, 2012) .

4.Scanning Electron Microscopy (SEM)

For more comprehension of fracture mechanisms, have been observed by SEM. For interpretation of the damage mechanism occurred during loading, the fractured surface is chosen for SEM. In this way, the specimens are coated in gold, having been prepared for viewing fracture surface with a scanning electron microscope. The primary modes of damage observed in the specimens tested are illustrated in the photomicroscographs of the fracture surfaces as shown in Figure 3, (a) shows matrix cracking, fiber-matrix debonding, fiber pull-out and breakage in a $[0]_{6s}$ specimen. In a $[45/-45]_{6s}$ specimen, fiber breakage, fiber pull-out and breakage, matrix cracking were observed as shown in Figure 3, (b).

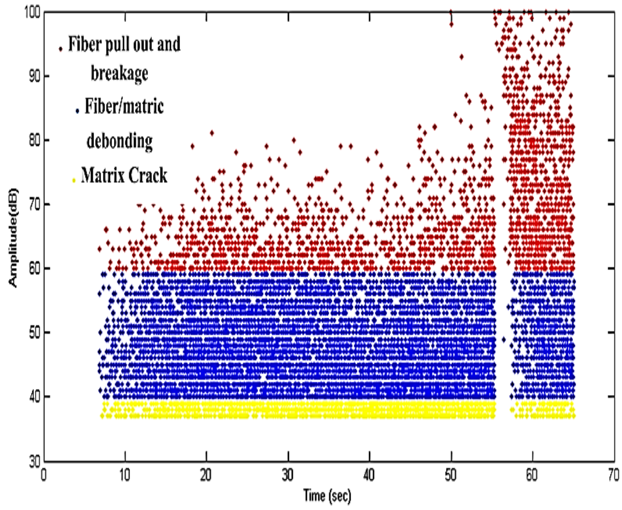


(a)

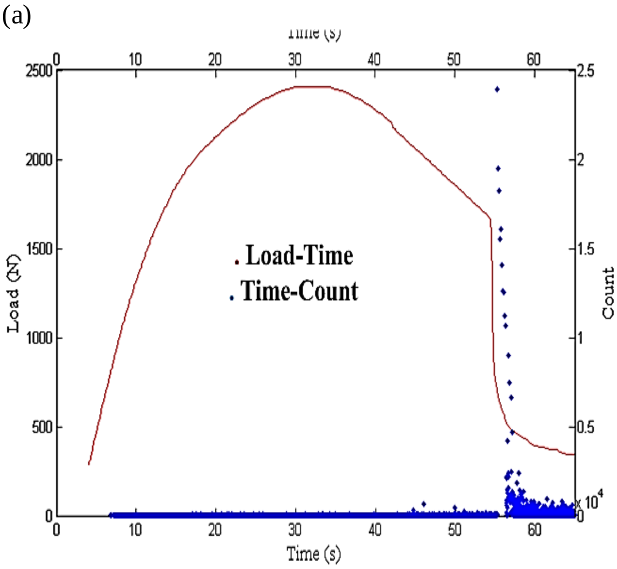


(b)

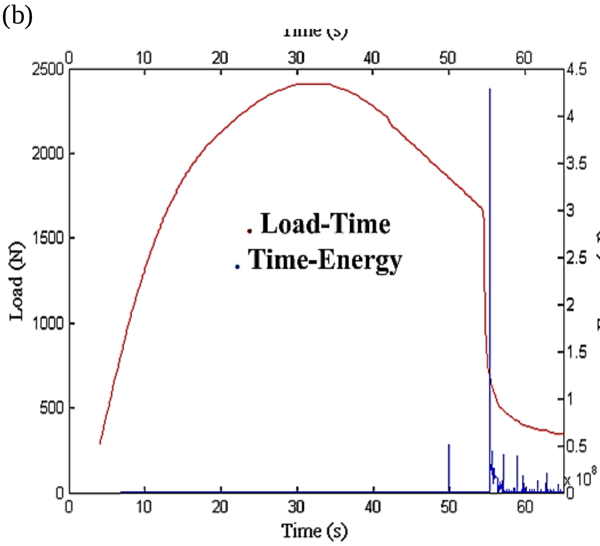
Fig. 3, (a) Microstructure of composite spesimen-2 after fracture by scanning electron microscope. (b), Microstructure of composite spesimen-3 after fracture by scanning electron microscope.



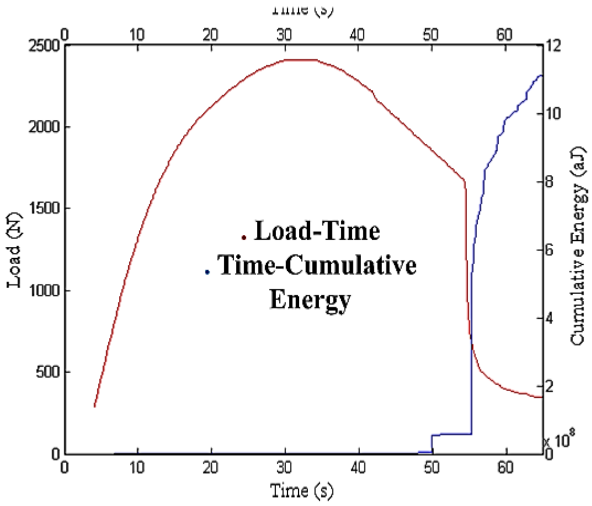
(a)



(b)



(c)



(d)

Fig. 4, Acoustic emission response for composite specimen-3: (a) time-amplitude curve, (b) Load-time-count curve(c) Load-time-energy curve, and (d) Load-time-cumulative energy curve at the moment of fracture.

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.

The real-time acoustic emission response is analyzed from the view of composite micro mechanics. From the analysis, the following conclusions are obtained:

Although the controlling failure modes can be identified, 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, 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. The variation of the count and especially cumulative AE Energy (Cum. Energy jumping) indicate that there is dominateor considerable damage having been occurred and it can be a criteria for knowing about the material life and its condition during loading.

AE testing is a powerful method for online detection and analysis of matrix, fiber and interface related active fracture processes in composite materials. A number of tools for identification and evaluation of damage stages and failure mechanisms exist. They are based on changes in AE activity or intensity features. SEM and AE analysis allowed working out the damage process and chronology.

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