KINETIC DAMAGE ANALYSIS OF COMPOSITE MATERIALS USING ACOUSTIC EMISSION

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Abstract

Fiber reinforced composite materials have been increasingly used as structural material in airplanes, because of their high specific stiffness and strength. Structural design and non destructive test techniques have evolved as increased emphasis has been placed on the durability and damage tolerance of these materials. This work presents the results of the damage kinetic of carbon fiber reinforced polymer using the acoustic emission under solicitations. The correlations between acoustic emission parameters and damage mechanism are identified, and then confirmed by microscopic observations. This review will emphasize the roles that AE can play as a tool for the composite materials, damage mechanisms, and characterization of damage evolution with increasing time or stress, the localization and origin of damage, quantification of crack size based on energy release from concrete structures in the field and reduction in the numbers of test specimens required in various studies.

Keywords: composite material; damage; correlation; mechanism; localization

1. Introduction

Composite materials find more applications in the realization of structural parts of various dimensions in many industries such as Aerospace, The car manufacturing, the nuclear, the biomedical engineering...

The matrix micro cracking which is chronologically the first mode of damage arising during the load of a composite structure;

- The breaking of the fiber-matrix interface;

-The delamination.

- The breaking of fibers. Many studies have attempted to develop methods for understanding these mechanisms using acoustic emission. The most parameter used is the amplitude of the acoustic emission signals. The work of Che and al, Chen Karandikar and al. [1] , Kim and Lee [2], Kargers–Koscsis and al [3], Kotsikos et al.[4] ,Ceysson et al [5] , Benzeggagh et al.[6] ,Bouchaib et al [7], on different families of composites and the tensile stress and or on bending static or on fatigue show the interest to exploit this acoustic parameter.

These various studies, have led us to do a multiparametric analysis of acoustic emission signals on woven composite bolted assemblies having various types of geometry and stacking sequences during monotonic tensile stresses followed simultaneously by D.I.C and A.E, then confirmed by the analysis in a scanning electron microscopy (SEM).

2 Materials and specimens

The material studied is a laminated composite carbon/epoxy G803/914. Each layer of this dry unidirectional fabric has a thickness of 0.13 mm. The characterization tests of the composite material allowed the determination of the experimental values which are: *Ex* = *Ey* = 41810 MPa ; *Ez* = 5000 MPa. $\nu_{xy} = \nu_{yz} = \nu_{zx} = 0{,}29$ *Gxy* = 16205 MPa.

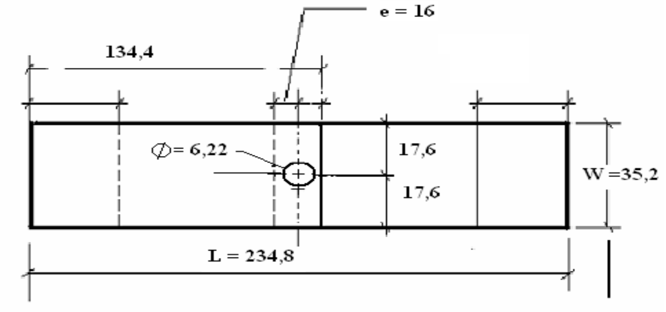


Fig.1 Assemblage single lap simple shear

3. Result and Analysis

.Among full field measurement techniques, Digital Image Correlation (DIC) is fast emerging because of its versatility and simplicity of use []. It consists in evaluating displacement fields corresponding to a series of (white light) pictures taken at distinct stages of loading. If the natural texture of the material is not sufficient for tracking accurately the displacements, a random speckle is usually sprayed onto the surface. Two gray level images I and h (I stands for the reference picture and h that corresponding to the deformed stage) are related through the local passive advection of the texture by a displacement field u:

2.1. From images to displacement fields

Among full field measurement techniques (Rastogi, 2000), Digital Image Correlation (DIC) is fast emerging because of its versatility and simplicity of use. It consists in evaluating displacement fields corresponding to a series of (white light) pictures taken atdistinct stages of loading. If the natural texture of the material is not sufficient for tracking accurately the displacements, a random speckle is usually sprayed onto the surface. Two gray level images f and g (f stands for the reference picture and g that corresponding to the deformed stage) are related through the local passive advection of the texture by a displacement field u:

$$g(x) = f\big(x + u(x)\big) \qquad (1)$$

The problem consists in identifying the best displacement field by minimizing the correlation residual $\int \emptyset^2 dx$
over the whole region of interest, where

$$\varphi(x) = \left|f\big(x + u(x)\big) - g(x)\right| \qquad (2)$$

The minimization of $\emptyset$ *is* intrinsically a non-linear and ill-posed problem. For these reasons, a weak form is preferred by adopting a general discretization scheme

$$u(x) = \sum_{n \in N} u_n \psi_n(x) = [\psi(x)]\{u\} \qquad (3)$$

where ψ_n are the vector shape functions, and un their associated degrees of freedom. In a matrix–vector format, $[\psi]$ is a row vector containing the values of the shape functions, ψ_n, and $\{u\}$ the column vector of the degrees of freedom. After integration over the domain Ω, the global residual is defined as

$$\phi = \int\int_{\Omega} |f(x + [\psi(x)]\{u\}) - g(x)|^2 \; dx \qquad (4)$$

.At this level of generality, one may choose to decompose the displacement field on a ‘‘mechanically meaningful” basis. When no simple behavior is expected, one may use a ‘‘simple” Finite Element kinematic basis (Sun et al., 2005). Here, classical bilinear shape functions associated with quadrilateral 4-node elements (or Q4) (Besnard et al., 2006) are chosen. It is referred to as Q4 Digital Image Correlation (or Q4-DIC). The measured displacement fields are next used as inputs for an independent damage law identification procedure, based on the same kinematic description.

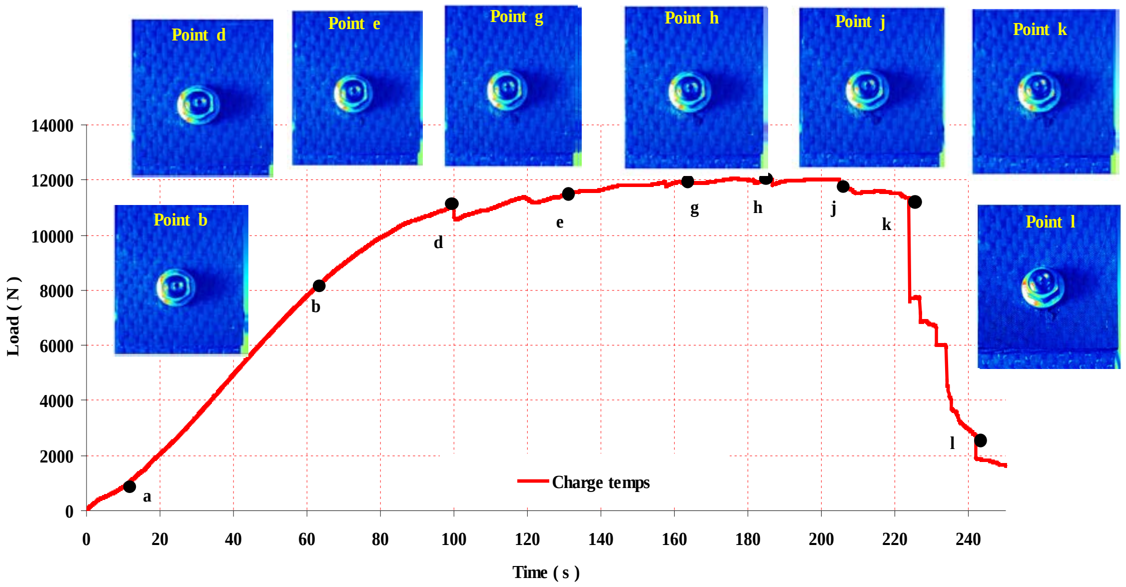


Fig. 03 Images taken by the DIC techniques on different characteristic points of the curve loed versus time during the tensile test until failure.

Figure 3 shows the variation of the load as a function of time during a tensile test of a bolted assembly belonging to the group, followed by the cumulative amplitudes of the four sensors

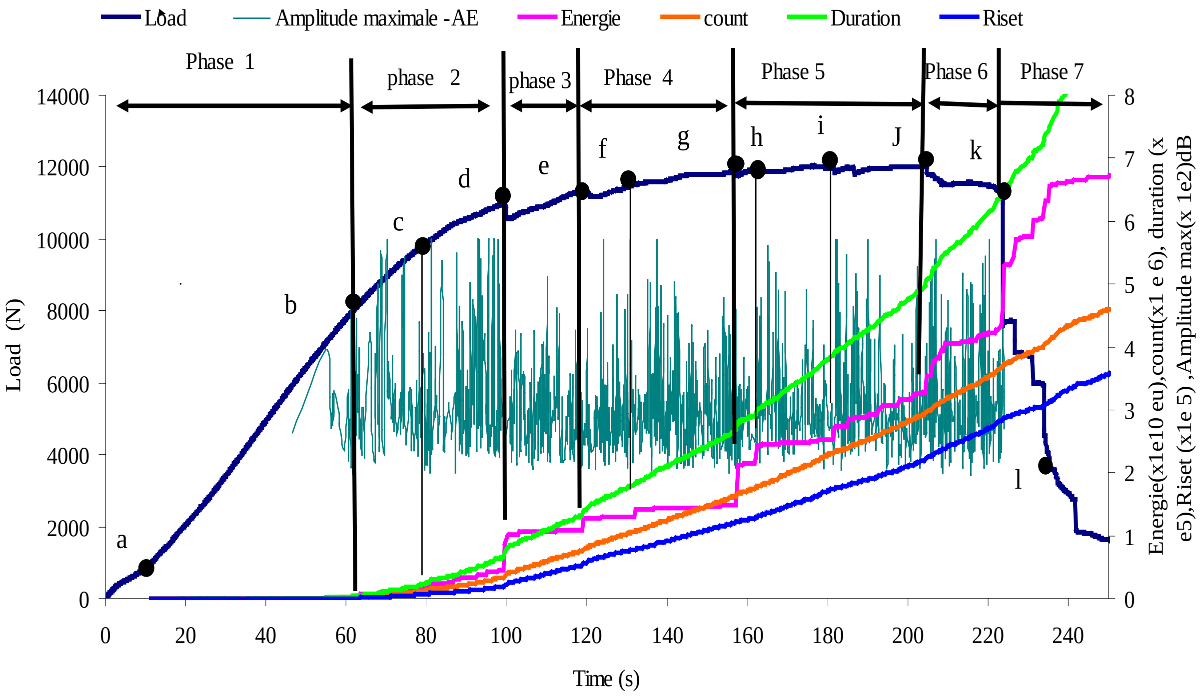


Fig.04 Time as a function of Loading followed by the acoustic parameters signals: maximal Amplitude, the energy, the count

The location is to determine the coordinates of the area where acoustic event has occurred. Thus, the use of sensors allows the location of acoustic output source (Fig.5 (1)). The most commonly used method is to measure the differences in arrival time (ΔT) of the same signal to a plurality of sensors distributed over the structure. The measurement of (ΔT) is usually triggered by the arrival of the acoustic emission sensor reaches the first wave and closed by its passage of last sensor [38]. When the difference in time of arrival of the same signal is given for four sensors, the locus of points at which the source belongs is defined by:

$$V.\ \Delta T = \text{const} \tag{5}$$

Where, v is the velocity of wave propagation, assumed to be constant whatever the direction and distance of propagation.

For elastic wave propagation in substrate, with the increase of propagation distance, the amplitude of vibration and the energy reduce gradually. The acoustic signals were acquired at four spatially separate points using acoustic sensors mounted on the substrate in rectangular array as shown in Fig.5. The sensors captured signals are mathematically modeled as:

$$\begin{bmatrix} S_1(t) = F(t) + g_1(t) \\ S_2(t) = \partial F(t - M_1) + g_2(t) \\ S_3(t) = \partial F(t - M_2) + g_3(t) \\ S_4(t) = \partial F(t - M_3) + g_4(t) \end{bmatrix} \tag{6}$$

where S1(t) - S4(t) are sensors outputs, F(t) is the AE source signal, g1(t) - n4(t) are un-wanted signals, ∂ is attenuation factor caused by the acoustic path differences and D1-D3 are time differences. In this study, the geometrical coordinates of S1 position Is considered as (0, 0) and others are chosen following S1. The position of AE source is O(x, y). The sensor-source distances can be obtained by:

$$\begin{bmatrix} O_1 = V \times t_1 \\ O_2 = V \times t_2 \\ O_3 = V \times t_3 \\ O_4 = V \times t_4 \end{bmatrix} \tag{7}$$

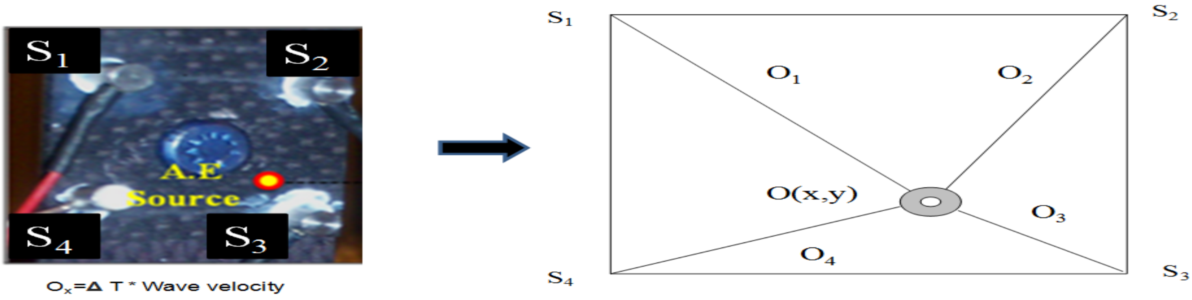
V is the value of propagation velocity, it is the time of propagation of waves from acoustic emission source to sensor Si. The time-delay of propagation of acoustic waves from acoustic source to S1 and S2 can be determined as:

$$\Delta t_1 = t_1 - t_2 = \frac{O_1 - O_2}{V} \tag{8 }$$

in AE source localization propagation velocity and wave arrival times are the most important parameters. The time delay between two collected signals (P1(t), P2(t)) can be determined using cross correlation-function as:

$$R_{P_1P_2}(\tau) = \sum_{t=1}^{T} p_1(t)\, p_2(t + \tau) \tag{9}$$

The parameter (τ) (which maximizes the cross-correlation function $R_{p_1p_2}(\tau)$ provides anestimation of time delay. In Eq. (3) it is found that a constant wave velocity in substrate must be known in order to locate acoustic emission source.



(1) (2)

Fig.5. (1) location of acoustic output source, (2) Sensors and acoustic source position for 4 channel position, O(x,y) acoustic source position, and O_1, O_2, O_3, O_4 represent the sensor-to-source distances .

4. MICROSCOPIC OBSERVATIONS

Figure 5 presents microstructure of composite specimen after fracture by scanning electron microscope. Meanwile figure 05 shows Magnification of microstructure of composite specimen C after fracture by scanning electron microscope. An important fragmentation zone of the plies at 45° is observed. These defaults can be at the origin of inter-ply delamination once they reach the interface.

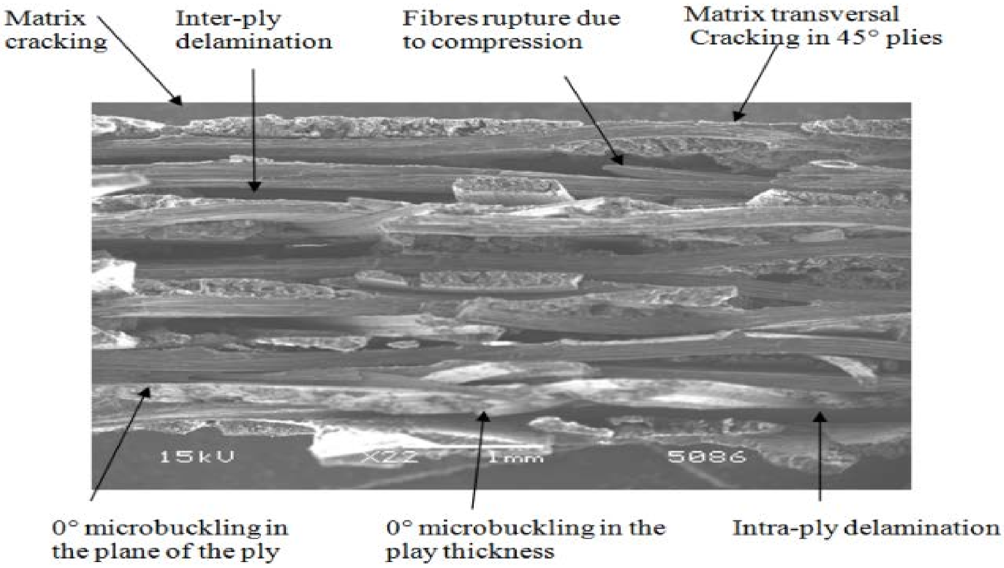


Fig.05 Microstructure of composite specimen after fracture by scanning electron microscope.

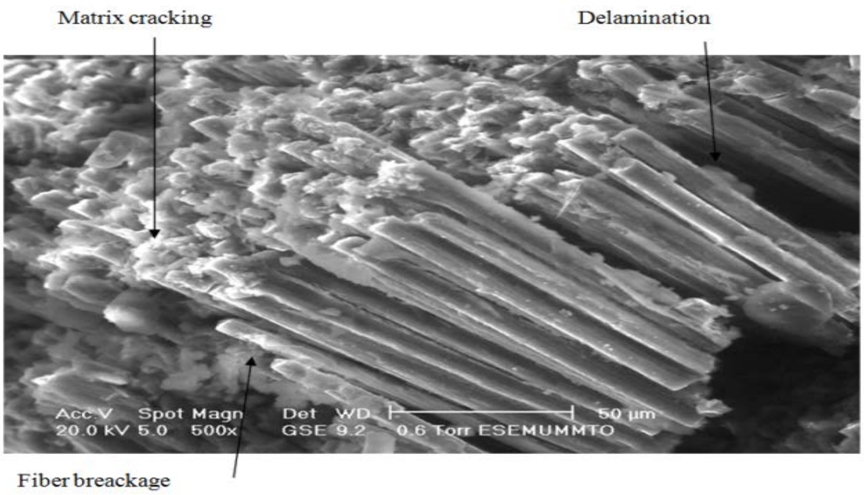


Fig.06**.** Magnification of microstructure of composite specimen C after fracture by scanning electron microscope.

4. CONCLUSION

The coupling of the acoustic emission technique (A.E) and (C.I.D) has highlighted the different phases describing the global mechanical behavior of bolted assembly. Experimental test has shown initial damage in woven composite bolted assembly (carbon fiber /epoxy) of the specimen A, B, and C occurring respectively at 83%, 61% and 28% of final bearing failure.

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