Fatigue damaging analysis of a glass/polyester composite with acoustic emission

M. Benantar[1,a], M.A. Belouchrani[1,b] and Z. Aboura[2,c]

[1] Laboratoire Génie des Matériaux, Ecole militaire Polytechnique, BP 17 Bordj El Bahri, Alger, Algérie.

[2] Laboratoire Roberval, Université de Technologie de Compiègne, Compiègne, France.

[a] m.benantar@yahoo.fr, [b] nbelouche@yahoo.fr, [c] zoheir.aboura@utc.fr

Keywords: Glass / polyester, damage, acoustic emission.

Abstract. Acoustic emission is a nondestructive controlling method which has proven its use in damage tracking of composite materials. In this paper, this technique is applied on glass/ polyester composite. We focus on mechanical behavior of these materials under fatigue loading. The results of such test allowed us not only, to plot the Wöhler's curve but to evaluate the damage level at a given loading, as well. We have also processed the acoustic signals in order to detect phenomena responsible on material properties degradation. The originality of our work is that the scatter plot of energy of each hit versus the duration, revealed a V-shaped couple of branches. The first branch corresponds to observed damage mechanism due to static loading/or and to the dynamic behavior such as rubbing, whereas more important damages such as local micro-buckling correspond to the second branch.

Introduction

The wide industrial use of composites reinforced with glass fiber is mainly due to their numerous advantages. Their exceptional resistance to fatigue and shock, their mechanical characteristics and properties together with their low weight compared to aluminum alloys, made them extensively used in many applications such as aerospace industry. Generally, the fatigue of highly-performing composite materials depends on the nature of the fibers and resins as well as the adopted shaping process. Dimensioning of composite materials made structural parts, is still an open issue. Under cyclic loading, the mechanical behavior, damage and ruin of the material and structure strongly depend on complex phenomena, occurring at the microscopic level: strain localization, initiation, propagation of microcracks [1, 2]. The acoustic emission technique seems to be effective in monitoring the various failure mechanisms of these materials [1, 2, 3, 4].
In this paper, we focus on the study of glass/polyester composite damage in terms of mechanical properties degradation and acoustic signatures detection of damage mechanisms using the acoustic emission technique.

Experimental set up

The test specimens were made from plates with 12 taffeta cloth layers for a thickness between 2 to 3 mm. The used resin is polyester which has a Young's modulus of 4 GPa and a tensile strength of 52 MPa. 250 mm length and 25 mm width specimens were produced.

Fig.1. Test specimens.

In our study, fatigue tests are performed at imposed loading. Used amplitudes were derived from preliminary tensile quasi-static tests. We recall that several loading levels were considered, and three samples were tested until failure at each level with a frequency of 2 Hz and load ratio R = 0.3. These fatigue tests were performed on a servo-hydraulic machine INSTRON 1341 with a loading capacity of 25 kN. The strains are measured by an Instron extensometer with a maximum extent of 2%.

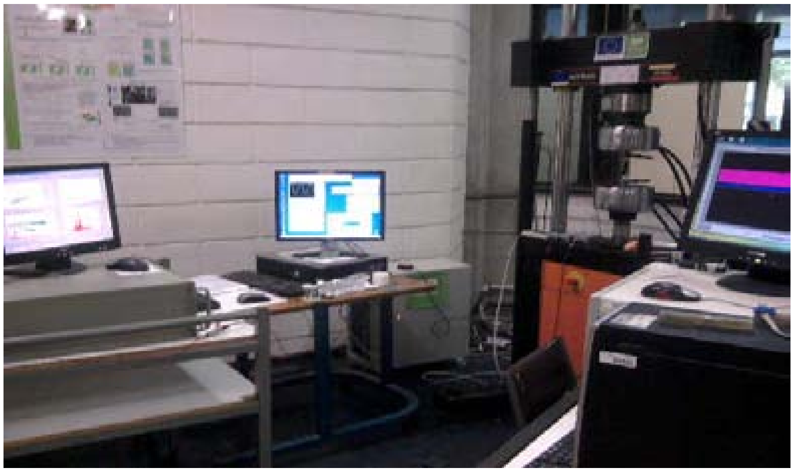


Fig.2. Machine and instrumentation for fatigue tests.

To track the status of the material and the evolution of its damage, a chain of acoustic emission is used. This monitoring of acoustic emission testing was performed using two resonant sensors (micro PAC-80) of 10mm in diameter.
Acquisition is done via the software supplied with Euro Physical Acoustic capture card (Figure 2). The technique of acoustic emission needs some parameters setting to allow comparison tasks [7]. Emissions have to be recorded in the best conditions and have to correspond to the material damage but not to machine parasites. For our tests, the parameters are fixed as shown in Table 1.

Tab.1. Parameter Settings acquisition.

Parameter	**value**
PDT (µs)	200
HDT (µs)	800
HLT (µs)	1000
Threshold (dB)	45
Distance between sensors (mm)	130

Results and Discussion

The fatigue tests are made for the material as follows: initially, a rise in static tensile (speed 1kN / s) is applied to achieve the level of average loading corresponding Fmoy. Then the specimen is subjected to cyclic loading between the value of Fmax and Fmin loading.

1. Analysis of mechanical data

The fatigue tests conducted at various loading levels allowed plotting of the Wöhler curve for the material (Figure 3).

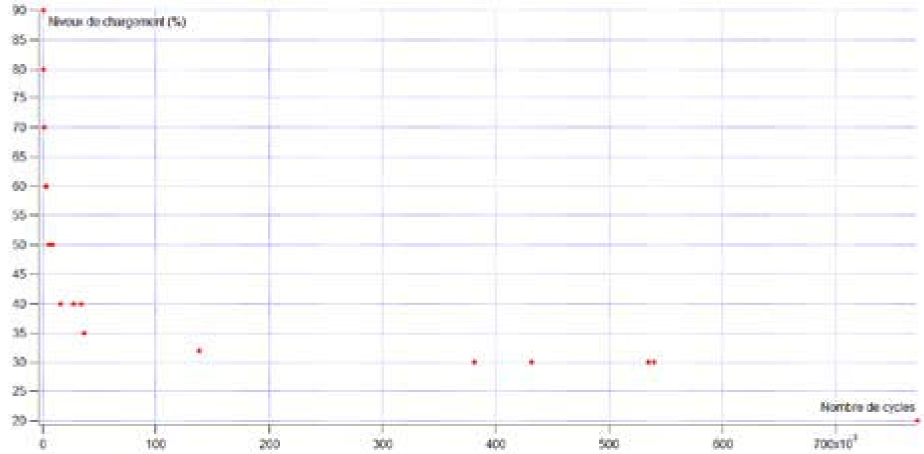


Fig.3. Wöhler curve for the used material.

On this curve, it can be noticed that for less than 20% loading, life time of the material becomes more important and no damage is observable. For the material damage kinetics study, decreasing of stiffness is used as damage indicator. Hence, the damage variable used to plot the evolution of damage versus the number of cycles is the elastic stiffness E. The measure of this stiffness allows assessing the value of damage using the following relationship:

$$d = 1 - \frac{E}{E_0},$$

where E0 is the elastic stiffness of the undamaged material.
Taking the example of the specimen charged at 70%, the evaluation of rigidity during the loading cycle (obtained on the stress - strain curve of Figure 4) for certain percentages of the number of cycles at break has allowed deducing the evolution of damage versus the number of cycles.

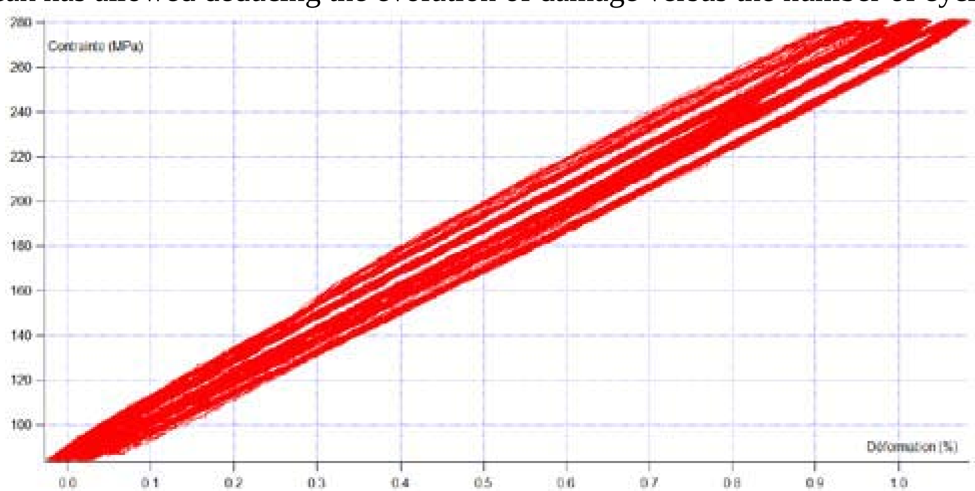


Fig. 4. Stress-strain curve.

In figure (5), we notice a nearly linear fast evolution of damage coefficient followed by a first stage of stability. Then, we see a hop followed by a second stage of stability at 70% the number of cycles to failure, where there has been a fast evolution of the coefficient of the damage until the final break. These hops and successive stages can be due to the chronological occurrence of different damage mechanisms.

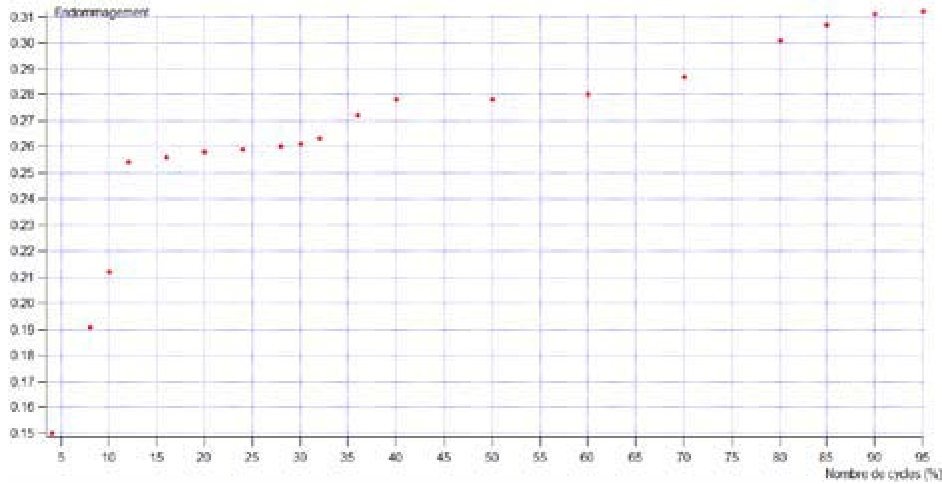


Fig.5. Evolution of damage versus the number of cycles.

Figure (6) gives the evolution of the modulus of rigidity versus on the number of life cycle to break. We can see a fast decrease of the module up to 12% of the life cycle (high slope). After this point, the modulus of the material begins to stabilize at an almost fixed value then, there has been a second decrease followed by a second stage. From 70% of the life cycle to break, the material loses its rigidity rapidly until final failure.

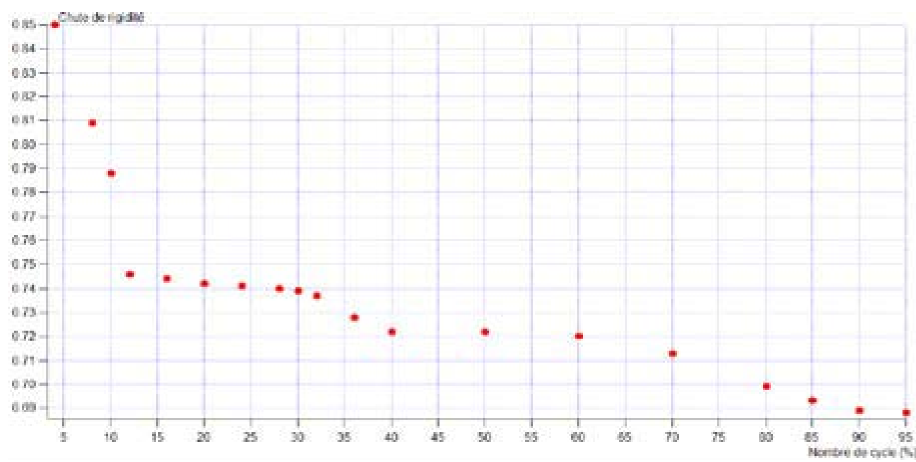
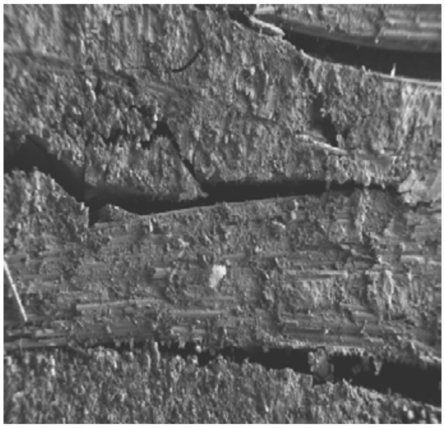


Fig.6. Evolution of decrease in rigidity versus number of cycles.

2. Observation with SEM

The final rupture of the specimen, during the tensile test with elastic relaxation, results from the presence of different damage mechanisms:

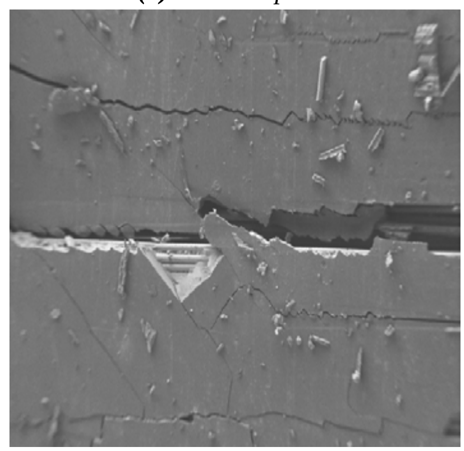
- Matrix rupture;
- Fiber/ matrix debonding;
- Delamination between layers;
- Fibers rupture.



***(a)** Delaminating*

***(b)** Fibers rupture.*

***(c)** Fiber-matrix depondind*



***(d)** Matrix rupture*

Fig.7. Observed Damage mechanisms.

3. Analysis of acoustic emission data

Correlation analysis applied to acoustic emission data, obtained during fatigue tests, shows the possibility to distinguish two families of signals forming a "V" for the correlation between energy and duration. However, the display of energy versus the duration for each hit gives an original visualization of the test. Until now, we are unable to tell if we are in presence of events that occur during the loading or the unloading of the specimen. However, the phenomena related to the "V" and having a rather large energy are the source of the material damage that leads to ultimate ruin.

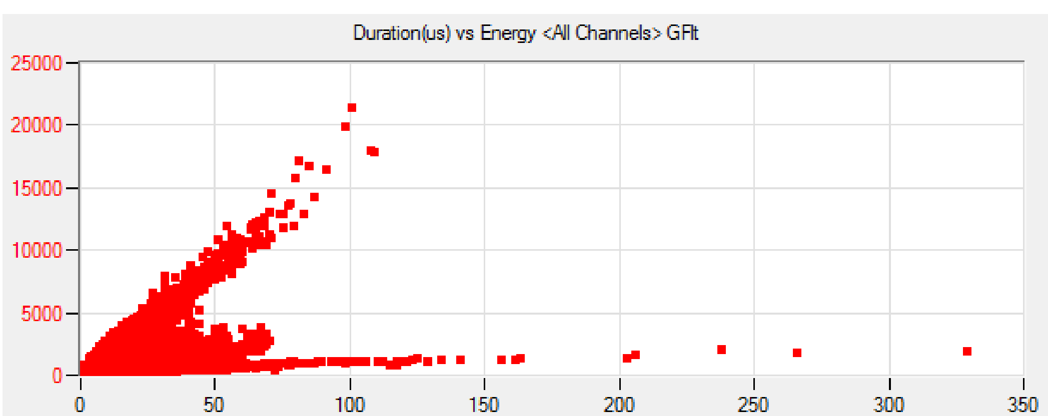


Fig.8. Correlation between duration and energy of acoustic hits.

The preprocessing of these data shows that the acoustic events presented during a fatigue test are separated by the correlation analysis. To determine what type of phenomena the signals of the two branches are related to, several investigations were made. First, the static tests on the same material give hits only on the first branch (the vertical), the second branch may represent phenomena different from those observed in static. Regarding the nature of the hits present in each branch, we found out that the major part of friction and micro-buckles that may occur after release of the composite, are only present in branch 2. These micro-buckles are isolated or discalced fibers which cannot return to their initial state.

Conclusion

In this paper, a set of fatigue tests has been performed on the studied material. The acoustic emission technique has been used to monitor these tests to check the damage initiation and its evolution during the mechanical loading. The rigidity decrease is used as an indicator of damage for the material. Preliminary analysis of acoustic data showed that the correlation between duration and energy of the hits allows differentiating acoustic signatures of damage mechanisms from friction and micro-buckles phenomena obtained during fatigue tests.

References

[1] H. Nouri, (2009). MSc Thesis, University of ParisTech, France.
[2] S. Barre, M. L. Benzeggagh, (1994), Composites Science and Technology, vol. 52, issue 3, pp. 369-376.
[3] D. Scida, Z. Aboura, M.L. Benzeggagh, (2002), Composites Science and Technology, vol. 62, pp. 551-557.
[4] G. Kotsikos, J. T. Evans, A.G. Gibson, J. Hale, (2000), Composites Part A: Applied Science and Manufacturing, vol.31, issue 9, pp. 969-977.
[5] S. Huguet, N. Godin, R. Gaertner, L. Salmon, D. Villard, (2002), Composites Science and Technology, vol.62, pp. 1433-1444.
[6] J Henry, Z. Aboura, K. Khellil, S. Otin, (2011), Comptes Rendus des JNC 17 – Poitiers-France.
[7] A. Nielsen, (1989), Journal of Acoustic Emission, vol. 8, n° 1-2, pp 557-561.