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Acoustic emission monitoring of damage progression in Glass/Epoxy composites during static and fatigue tensile tests

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ABSTRACT

In this paper, static and fatigue behavior of Glass/Epoxy composite laminates are investigated. During experimental tests the gradual degradation and damage evolution in the composites tested were monitored using the acoustic emission method (*AE*). The specimens tested were made with different stacking sequences ($[0_2/90_2]_s$, $[90_2/0_2]_s$, $[0_3/90]_s$ and $[90_3/0]_s$) according to the vacuum infusion procedure. The analysis and observation of *AE* signals collected during experimental tests allow the identification of the various damage mechanisms, and detect those which are the most critical, leading to the failure of the tested specimens. The accumulated damage is manifested by matrix cracking, inter-ply debonding, delamination and fiber breakage. The acoustic signals collected during the tests were analyzed by a classification method which consists of the *k*-means method and principal component analysis (*PCA*). The results of the acoustic emission signals accumulated during static and fatigue tests are compared in order to assess and evaluate the intensity of these activities for each stacking sequence. The distribution of amplitude and the time dependency of the different damage modes are shown in this study.

1. Introduction

Composite materials are increasingly being used in a variety of industrial applications, especially in aerospace and automotive. These structures are more advantageous as compared to other traditional metallic materials due to their high mechanical performance, high resistance to fatigue, lightness, hardness, flexibility and high flexural [1–5]. Laminated composite materials offer one of the most important benefits to designers and manufacturers which allows them the freedom to tailor the properties and response of the structure to given loading conditions to obtain the maximum weight efficiency. Recent advances in materials and their implementation have resulted in further improvement and increased uniformity in composite laminate properties. But this has resulted in more complex mechanical behavior during static and fatigue testing. In that fact, engineers and research scientists are required to reconsider cyclic loading as an important factor which may lead to the fracture of these materials. However, it's more complex to characterize their fatigue behavior compared to metal materials due to their micro-structural composition (anisotropy, heterogeneity, fiber/matrix interface properties) [6,7]. The gradual deterioration of composites during fatigue is mainly due to changes in stiffness during cycles which further cause a continuous redistribution of stresses, strains and a reduction of stress concentration inside a structure or component [8–10]. Among all the current techniques for structural health monitoring and automated crack detection and location, the acoustic emission (*AE*) technique presents one of the most widely used and promising methods which is able to assess the actual state (when and where final failure is to be expected) of any component subjected to various and repeated loading conditions [11–13]. This technique represents the generation of transient ultrasonic waves in structures, when the material is deformed and fissured under the external mechanical, chemical or thermal action. Signals generated by the various damage mechanisms are collected by a piezoelectric sensor, then amplified and analyzed to provide the signal of sound emission [14]. The acoustic emission technique offers several advantages over other non-destructive testing techniques. It allows us to detect micro-cracks and to keep track of damage initiation and evolution in real time and throughout the test period without interruption. This technique can provide an early warning before final failure, which can improve safety and durability of structures and mechanical components. The acoustic emission technique is one of the easiest non-destructive testing methods as it requires only the attachment of small piezoelectric sensors to the

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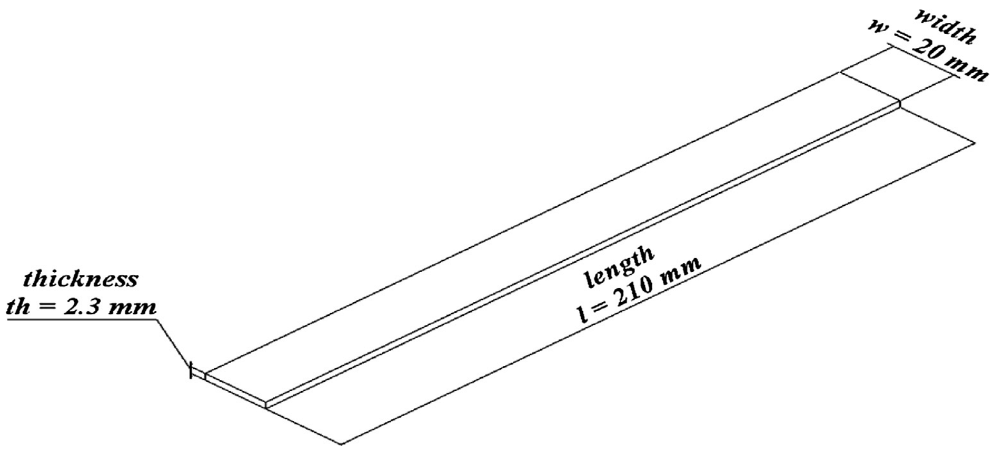

Fig. 1. Schematic illustration of the specimen dimensions used for static and fatigue tests (in mm).

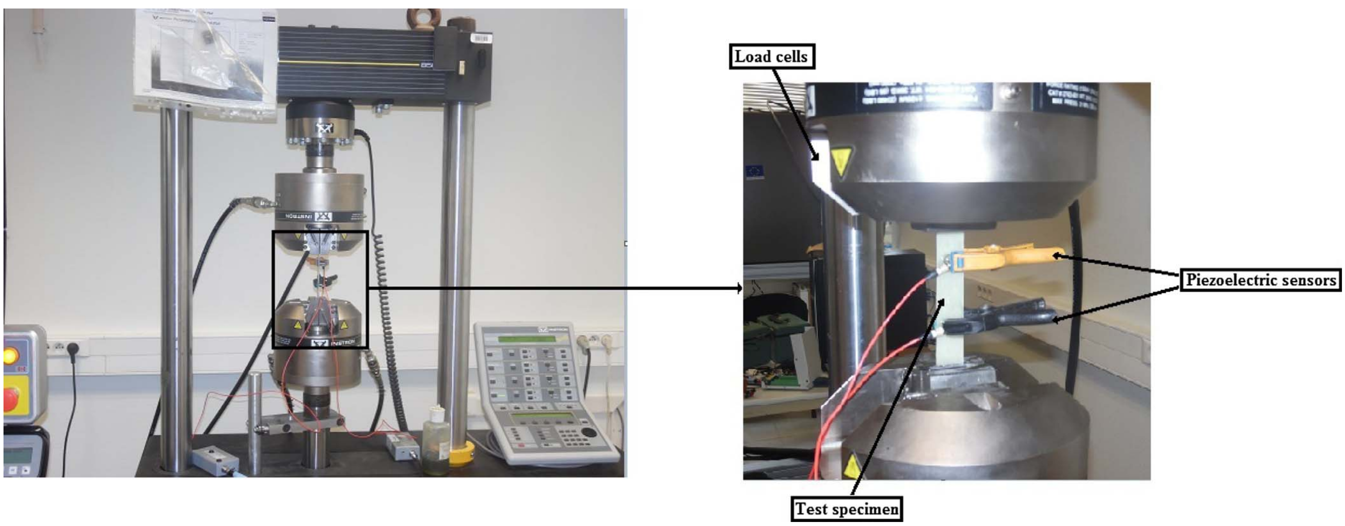

Fig. 2. Experimental equipment.

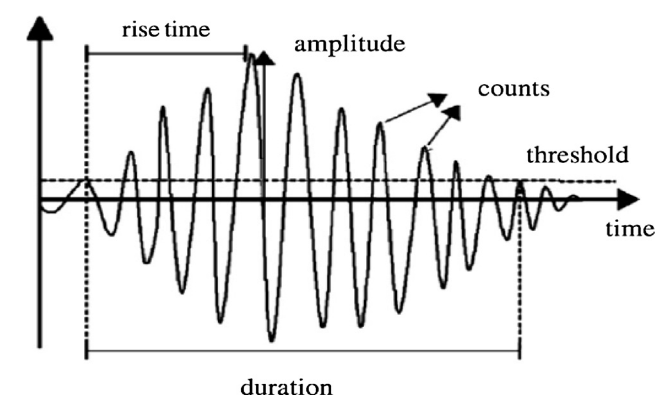

Fig. 3. Common waveform parameters calculated by the acquisition system for each *AE (Emission Acoustic)* event.

Table 1
Mechanical properties of Glass fiber.

Glass fiber properties				
Areal density	Tensile strength	Poisson's ratio	Strain to failure	Tensile modulus
300 g/m^2	2500 MPa	0.25	4.8%	74 GPa

Table 2
Mechanical properties of Epoxy resin.

Epoxy resin properties		
Young's Modulus	Tensile strength	Flexural strength
2.9–3.2 GPa	74–77 MPa	115–120 MPa

surface of the structure without significantly affecting the mechanical behavior of the tested material. In order to discriminate and identify the different damage modes from the *AE* signals detected, many researchers have used multiparameter statistical analysis including different methods of classification and clustering [15,16]. Multiparameter analysis techniques have been developed in parallel with advances in computer technology, which allow quick identification, easily relevant parameters, and classification of acoustic signals and events into different families. Previous studies and research were done through *AE* parameters such as counts, amplitude, duration, rise time and energy. Bussiba et al. [17] used the acoustic emission technique during cyclic tests performed on C/C composites, in order to track the damage accumulation profile in terms of *AE* parameter such as count rate and cumulative counts. They were able to point out the possible fracture sequence events during experimental tests. Ben Ammar and al. [18] have used the *k*-means algorithm in order to discriminate the various damage mechanisms leading to the failure of composite sandwich materials. The aim of the *k*-means method is to partition *n* observations into *k* clusters by the minimizing the sum of squared distances between