ACOUSTIC EMISSION APPROACH TO QUANTIFY DAMAGE EVOLUTION

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Abstract

This paper deals with establishing efficient approach to quantify the physical aspects in composite material degradation, mainly the damage process, its evolution, and the variability due to the heterogeneity of the micro-structure. The proposed study aims to compare results of two approaches used in the macroscopic characterization of the damage initiation under quasi-static loading. The discontinuous glass fibres confer to the material an anisotropic aspect to the overall mechanical behavior. Different glass fibres weight content (30%, 50%) are considered in order to compare with unfilled resin material specimens used as a reference.

1 Introduction

Glass fibres reinforced thermoplastic are increasingly used in transport industry as substitute for steels in structural components. However their specific mechanic behavior and their damage evolution aren't well known and controlled. Moreover, there are several techniques of non-destructive control which permit to monitoring a structure in real time. So in this study we used acoustic emission (AE) to quantify damage of a thermoplastic reinforced by discontinuous glass fiber. Previous studies show it's possible to link some acoustic signal's parameters with physical phenomena of damage [1], [2]. In this paper we analyzed damage phenomena by two methods. The first one is based on damage mechanics theory [3]. The evolution of a damage parameter is obtained by load-unload cycle's tests. The second method is considering the generated acoustic emission for failure events detection and processing. A cumulative damage parameter is defined as function of the Felicity ratio [2].

2 Experimental investigations

2.1 Material description

This composite consists of a thermoplastic Polyamide 6-6 (PA66) matrix reinforced by discontinuous glass fibres that confers an anisotropic aspect to the overall mechanical behavior. The glass fibres length is approximately about 100µm and their diameter is about 5µm. Two fibres weight contents (30% and 50%) have been chosen in order to compare with unfilled resin material specimens used as reference. Microscopic and tomographic observations show three directions to represent the reinforcement orientation. In the **figure 1**, the angles are measured relative to the injection's direction considered as the 0° direction. The tomographic study shows that part of fibres is oriented in the direction of injection, another part is oriented between 45° and 90° relative to the flow direction, and then a small part is randomly oriented (**figure 2**). The Fibres orientation has an influence on the damage phenomena and their importance [4]. In order to observe the anisotropic aspect in the material, some tests are realized on samples collected in two different orientations relative to the injection's direction. Dumbbell-shaped specimens are obtained by injection process and have 2 mm of thickness.

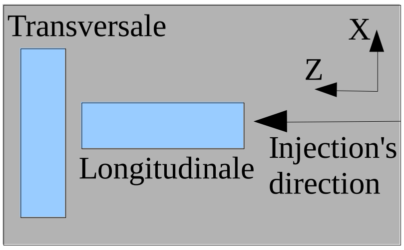

Figure 1. The material injection process.

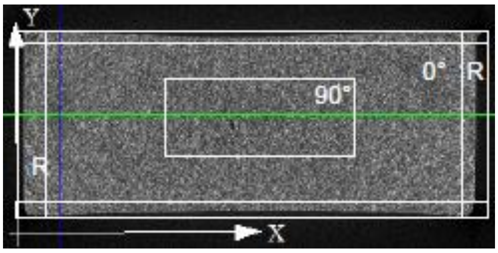

Figure 2. Fibres orientation in the orthogonal section view to the injection direction.

2.2 Tensile tests until rupture

A special thermal conditioning is required to ensure that material is dry. Specimen is placed in thermal enclosure during 24h before test, at temperature about 50° C. During tensile tests the temperature is controlled in the testing chamber and is fixed at 25° C. Time between the end of conditioning and the mechanical test beginning is also a key parameter and is fixed at 15min. The performed tensile tests had been conducted using a universal testing machine in quasi-static loading (1mm/min) to minimize the influence of the viscosity phenomena. The INSTRON 5884 machine is instrumented with a 150kN load cell. Note that the strain response is measured with an extensometer, load-unload cycle's test are controlled using the machine device displacement. Strain values for the "unloading/re-loading" cycles are fixed versus the ultimate strain defined by a tensile test until rupture.

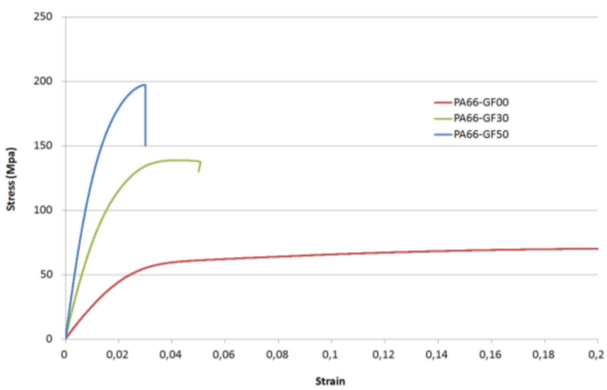

Figure 3. Typical stress-strain curves for studied material

Figure 3 presents the mechanical behaviour of the studied materials: PA66 unfilled matrix, PA66 30% and 50% weight content. The stress-strain curves show. Engineer parameters determined from this testing are in accordance with classical values given by the literature [5].

2.3 Acoustic emission approach

The proposed method is considering the generated AE signals for failure events detection and processing. To investigate the damage mechanisms, the signal is derived from discontinuous acoustic emission. According to previous studies [2], several parameters can be extracted from the result acoustic signals. However, it is necessary to establish relationship between the analyzed parameter and the physical phenomena. Meraghni and al [2] use only the amplitude to quantify damage response in a composite experimental approach.
In the case of the studied composite material, we use transducer with a bandwidth centered on 150 kHz. Then signals are amplified about 40dB and recorded using the software AEWin. The software Noesis is used for a results post-processing [6].

3 Identification of a damage parameter

3.1 Mechanical damage analysis

The first method is based on the classical mechanics theory. At macroscopic scale, the residual Young's modulus after damage, E_i, is measured for each elastic "unloading/re-loading" cycle. The well-known scalar damage parameter [4] is expressed such as:

$$d = 1 - \frac{E_i}{E_0} \quad (1)$$

Where E_0 is the Young's modulus of the virgin material. Meanwhile, the determination of E_0 is done with an important uncertainty in comparison with the variation of rigidity (between E_0 and E_1 for example). Thus the damage parameter undergoes a great variation due to E_0. Then an damage parameter derivated from the classical one is proposed: E_0 is replaced by E_1 which is definitely less sensitive to reading uncertainties (interception point between two curves)

As follows (**figure 4**), the first cycle is considered to identify the correct value for E_i.

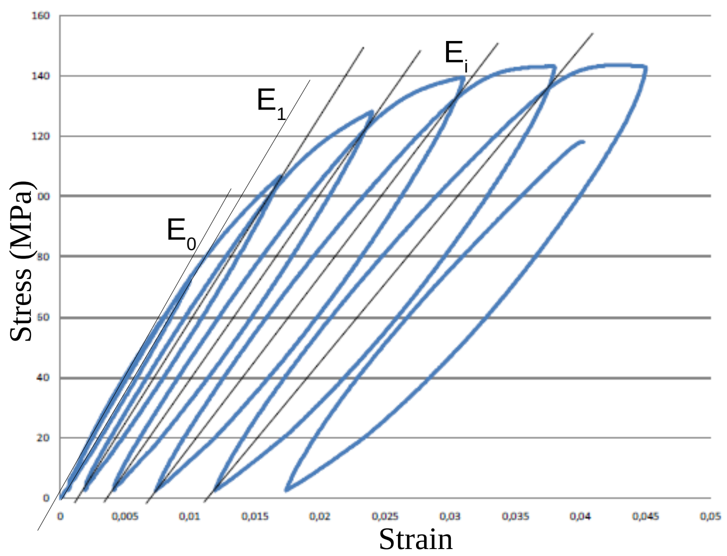

Figure 4. Young's modulus quantified on unloading/re-loading tensile tests.

3.2 Acoustic emission analysis: The FELICITY ratio

For metallic alloys, Kaiser Effect [5] reflects the irreversibility of the acoustic emission due to the apparition and the evolution of damage mechanisms. This irreversibility can be seen through the absence of acoustic activity during a cycle of unloading/re-loading for a load level lower than the previous one **(figure 5)**.

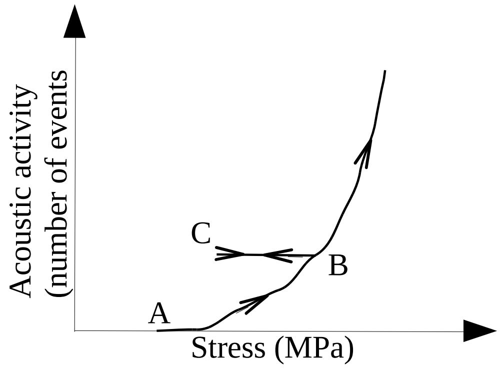

Figure 5. KAISER effect identified on a tensile test.

However, it seems to be different for composite material [2]. Indeed, acoustic activity starts before the load is equal to the previous level. This phenomenon is called Felicity Effect, and is due to viscous-elastic material properties. Using the identified load levels P_1 and P_2 (**figure 6**), we define a load ratio (2), called Felicity ratio and used to quantify the damage evolution:

$$R_f = \frac{P_2}{P_1} \tag{2}$$

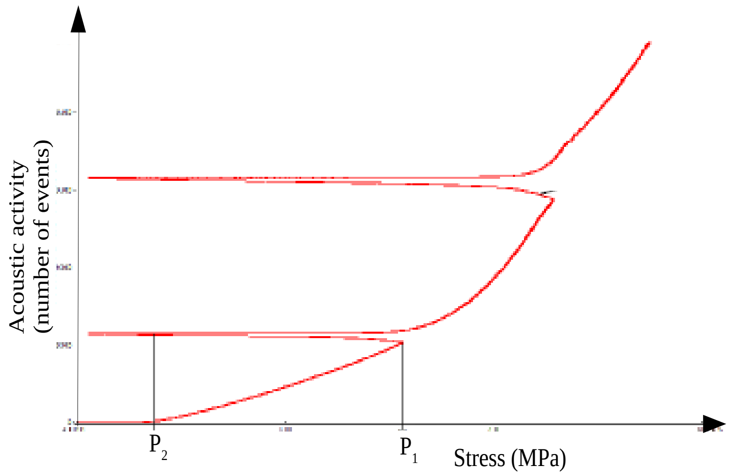

Figure 6. FELICITY effect identified on a PA66 GF30

A cumulative damage parameter is defined as function of the FELICITY ratio, R_f, as follows:

$$d = 1 - R_f^2 \tag{3}$$

The damage parameter, "d" remains isotropic in the two proposed methods.

4 Results – comparison and discussion

4.1 Validity of a scalar parameter for anisotropic material.

The classical damage parameter is defined as a scalar variable and is used as indicator to evaluate the stiffness reduction in the composite. It describes a macroscopic global behaviour independently of the microstructure and the fibres' orientation. Nevertheless, two different directions, longitudinal and transversal, on the material injection process have been performed in the aim to investigate the validity of a scalar parameter to represent the mechanical response. Indeed the distribution of reinforcement confers to the composite a microscopic heterogeneous aspect and an anisotropic mechanical behaviour. In similar material, damage accumulation occurs to complex degradation processes due to the statistical strength distribution. Thereafter, **figure 7** shows the damage parameter's evolution and seems similar in the two tested directions.

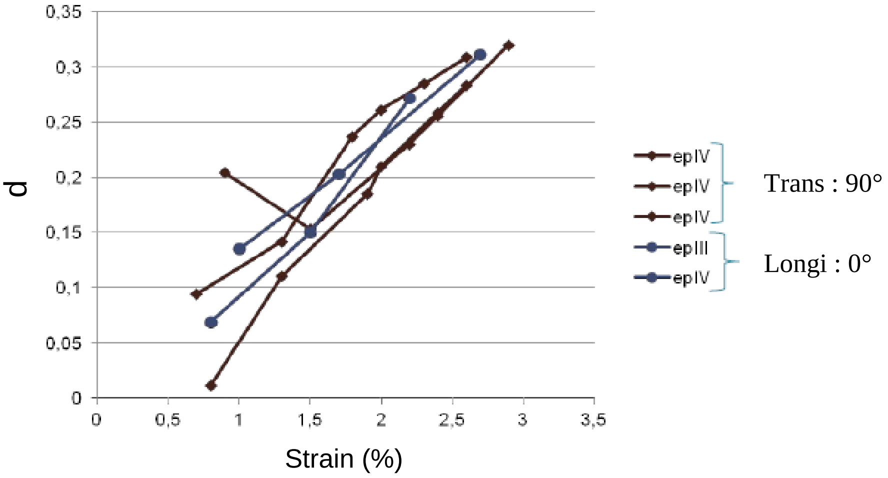

Figure 7. Damage parameter in two cutting directions for filled PA66

4.2 Comparison between parameter for unfilled PA66.

In the case of unfilled matrix PA66, experimental investigations exhibit different results of the damage analysis as presented in figure 8. The mechanics damage parameter shows a clear evolution and seems in line with the previous results. Nevertheless, one can note that the matrix damage is less important when using the acoustic emission approach through the felicity ratio (**figure 8**). The value of this parameter remains constant and does not represent the evolution of the damages leading to the failure of the material. Usually the acoustic events increase when the load level grows. But microcracking calculated density indicates that the unfilled matrix progressive degradation is mainly governed by the microcraks coalescence (**figure 8**). These defects coalescences are not completely take in account by the acoustic detection. Moreover the unfilled matrix ultimate strain is, normally, to 150% and due to technical limitation (displacement in the thermal chamber), only 20% of the ultimate strain has been tested. This result requires more investigation to contribute to unfilled matrix damage quantification using acoustic emission.

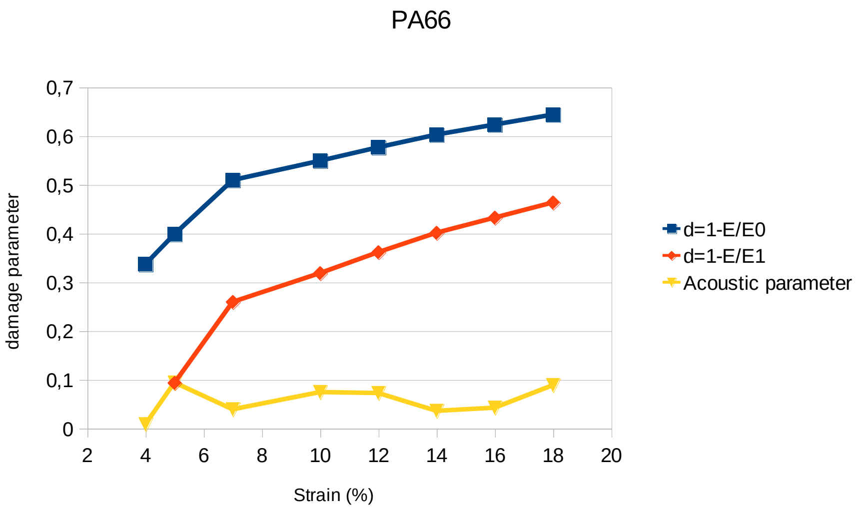

Figure 8. Damage evolution quantified using the classical method vs. the felicity ratio for an unfilled PA6-6.

4.3 Comparison of parameters for filled PA66

In the case of the fibres composites reinforced 30% (PA66 GF30) and 50% (PA66 GF50); the damage parameter quantified with the felicity ratio has similar evolution and magnitude than the mechanical damage parameter as reported in **Figure 9 and figure 10**.

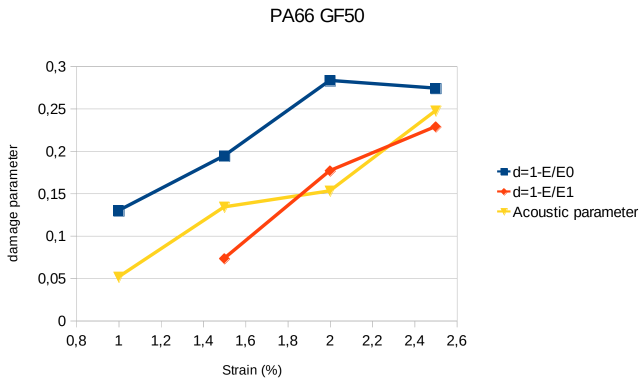

Figure 9. Damage evolution quantified using the classical method vs. the felicity ratio for a PA66 GF50 composite.

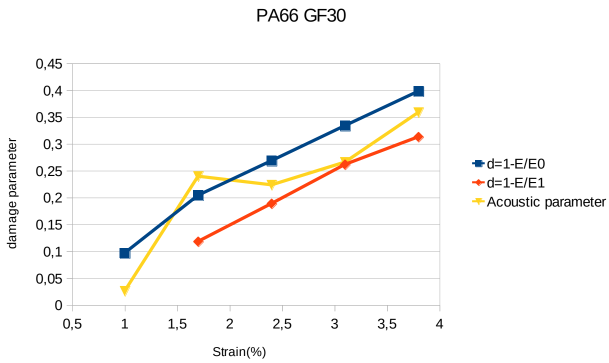

Figure 10. Damage evolution quantified using the classical method vs. the felicity ratio for a PA66 GF30 composite.

The experimental results show acceptable correlation between the two used approaches. We may observe singular values when measurement is affected by perturbation and noise within the tested specimen.

5 Conclusion

An experimental analysis based on acoustic emission has contributed to quantify the damage evolution on PA66 GFXX discontinuous fibres composite. Specimens with different glass fibres weight content (30%, 50%) has been tested and compared to the results of unfilled resin material used as a reference. Experimental results concerning the reinforced matrix show equivalent values of the acoustic emission damage variable compared to the classic mechanics processing result. Nevertheless, for unfilled matrix, the microcracks coalescence – which seems to be the main damage phenomenon – is not taken into account in the damage parameter determination; only the microcraks initiation density is considered. Indeed, a statistical method is applied to the obtained acoustic emission signals and, in order to complete the later information, a weighting process would be integrated to emphasize the microcraks coalescence contribution to a damage parameter.

So the use of acoustic emission during the test represents a powerful tool to quantify in real time the damage process evolution for such materials. The main difficulty of this technique remains to the quality of the data acquisition that must be refined to control the disturbances attributed to the test system.

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