MONITORING ACOUSTIC EMISSION DURING TENSILE LOADING OF THERMOPLASTIC COMPOSITES MATERIALS

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SUMMARY: Advance, parameters based acoustic emission AE techniques have been developed to evaluate damage and micro-failures in thermoplastic composites materials. This paper reports on an experimental investigation on mechanical and acoustic emission behaviour of polypropylene glass fibre composites that were tested in tension. An advanced digital signal processing techniques were also employed to identified fibre and matrix failure, pseudo-delamination, splitting (or cracking along fibres), and friction. These can be discriminated on the basis of different acoustic emission parameters. It is found that the tree parameters of acoustic emission data, the peak amplitude, event duration and event energy are the best indicators for characterisation the damage mechanics.

KEYWORDS: Damage mechanics, glass-fibres, polypropylene, acoustic emission (AE), tensile test, acoustics parameters, numerical acoustic system.

INTRODUCTION

The potential for determining damage severity in composite materials by monitoring acoustic emission during proof loading has been assessed. For this purpose polypropylene composites, reinforced by short glass fibre were investigated. The main objective of this work is to propose a new methodology based on acoustic emission and microscopic observations for follow chronology and understand damage mechanics and to assess this methodology as a measure for damage severity [1].

The potential of acoustic emission EA for providing reliable information and the ease with which it is applied in service depend largely on the AE instrumentation available. Significant improvements and modifications have been made on acoustic emission system including features for numerical acquisition and analyses. It allows also the different types of detection and location of defects, amplitude analysis, energy and duration analysis, counts, counts to peak and frequency analysis, which are coupled with data acquisition systems to display the information in real-time. The more numerical modern systems, coupled with qualified mechanical analysis of materials, enable determination not only of the existence of damage, but also of the type and extent of damage, and from this information attempts are being made to infer the location of specimen failure and the probable mechanisms of failure.

In this paper the influences of quality of the interface on the elastic behaviour, damage mechanics and the failure of these composites is studied.

The correlation between analysis of acoustics parameters and mechanical parameters permit to adapt and confirm, on these materials, the amplitude's distribution model [2]. On the other hand the results show a good correlation between amplitude, energy and duration of signal, and the statistics approach confirm us this results.

From the previous results we conclude that the acoustic emission control coupled to experimental approach of composites structures has been necessary to understand more damage and failure phenomenon.

Experimental procedure

Materials

The studied material is a thermoplastic composite with polypropylene matrix PP reinforced by short glass fibres. The following table gathers the essential properties of the two components of the composites.

Table 1: Components Properties.

characteristics		**polypropylene** (pp)	**Glass E Fibre**
Density	(kg / m 3)	905	2600
Elastic Modulus	(MPa)	1500 à 1700	73000
Shear Modulus	(MPa)	550 à 600	30000
Poisson Ratio		0,40	0,25
Stress Failure	(MPa)	32 à 35	2500
Failure Strain	(%)	200 à 1000	4,5

The samples used in this study are supplied by injection. The material to be injected PP is presented in the form of granulate colorless, translucent, with index of fluidity I = 12g/mn and 166 °c melting point. The fibres used are glass E with 4 mm length and 10 µm diameter approximately. Samples were produced using an injection machine of Fast-Inject type, equipped with a mould doubles impressed, controlled by computer. The realisation is done according to the ISO R527 standard. Parameters of injection (speed, pressure, temperature of injection, temperature of regulation of the mould...) were fixed preliminary by the operator.
The following figure presents various materials according to the essential parameters to study, figure 1.

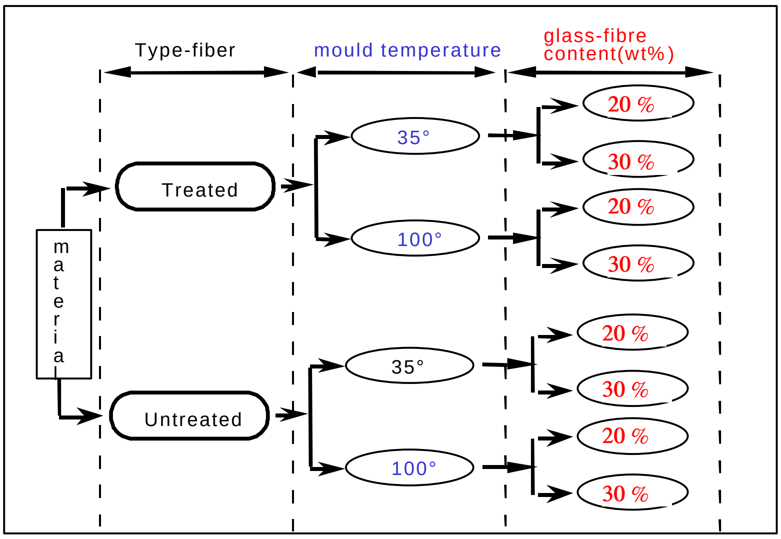
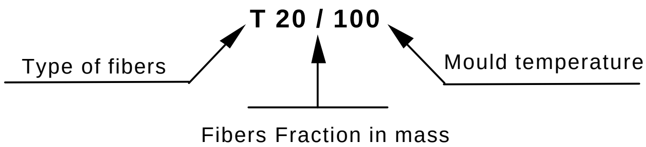


Fig. 1: Presentation of various studied materials.

In the continuation of the study, the materials used will be indicated as follows:



With:
T, indicate treated glass fibres: (oiled)

N, indicate untreated glass fibres: (not oiled)
Examples:
- T20/100 (composite PP reinforced by 20 % of treated glass fibres, injected at 100°C).
- N30/35 (composite PP reinforced by 30 % of untreated glass fibres, injected at 35 °C).

Tensile tests

The tensile tests are carried out on a static machine type INSTRON 1186. In addition to the signals of the acoustic emission, acquisition system collects the load applied to material and the extensometric sizes measured by the strain gages. All these data are stored and treated by a computer. The sample is instrumented by bi-directional gages to measure the longitudinal and transverse strain in the material.

Acoustic emission

The acoustic emission system used in this study consisted of the Physical Acoustics Corporation System Model AEDSP-32/16 & MISTRAS 2001. AEDSP-32/16B card provides high-speed and high-resolution digital waveform collection built in. The standard MISTRAS-2001 system comes complete with PC and AEDSP-32/16B card, enclosed in an industrial housing. The sampling of features is 2 at 10 MHz per channel, with lower noise (< 18 dB threshold) and the CPU selectable, 15 filters/channel (LP, HP, BP). The 2/4/6/ preamplifier is used with AE system that have their power supplied via the output signal BNC. Provide with 20/40/60 dB gain (switch select), this preamplifier operates with either a signal-ended or differential sensor. In our case the gain was 40dB and the plug-in filter was band pass [20 and 1200 kHz]. Acoustic Emission Signals are detected using a piezoelectric transducer (PAC MICROPHONE 80) and have a large range of frequencies from 200 kHz to 1MHz. A coupling fluid (Dough 428 Rhodorsil Silicone) is used to have a flawless contact between the transducer and the specimen.

Analysis of experimental results

The use of numerical acoustic emission systems makes possible to multiply the number of analysis but request to take precautions during the parameter setting of the system. Indeed the recording of the waveform on which are measured different acoustic parameters depends mainly on the choice of the system timing parameters. The timing parameters are Peak Definition Time (PDT), Hit Definition Time (HDT) and, Hit lockout Time (HLT).
The function of the PDT is to enable determination of the time of the true peak of the AE waveform. The main requirement is avoid false measurements being made on high-velocity, low-amplitude precursor subject to this, PDT should be as short as possible.
The function of Hit Definition Time (HDT) is to enable the system to determine the end of the hit, close out the measurement processes and store the measured attributes of the signal. In most Physical Acoustic Corporation PAC system the HDT must be at least twice as long as the PDT. The goal is to identify and describe events realistically. The HDT must be long to span over an intervals in which the signal to be measured falls bellow the threshold. Subject to this, the HDT should be set as short as possible, in order to permit, high data throughput rates and reduce the risk that two separate events will be treated as a single hit.
The function of Hit lockout Time (HLT) is to inhibit the measurement of reflections and late-arriving parts of the AE signal, so that data form wave arrivals can be acquired at a faster rate. The HLT circuitry is a non-triggerable one-shot, triggered by the time out of the HDT. The chose of these parameters is based on the waveform analysis and the frequency spectrum obtained from used materials, following figures.

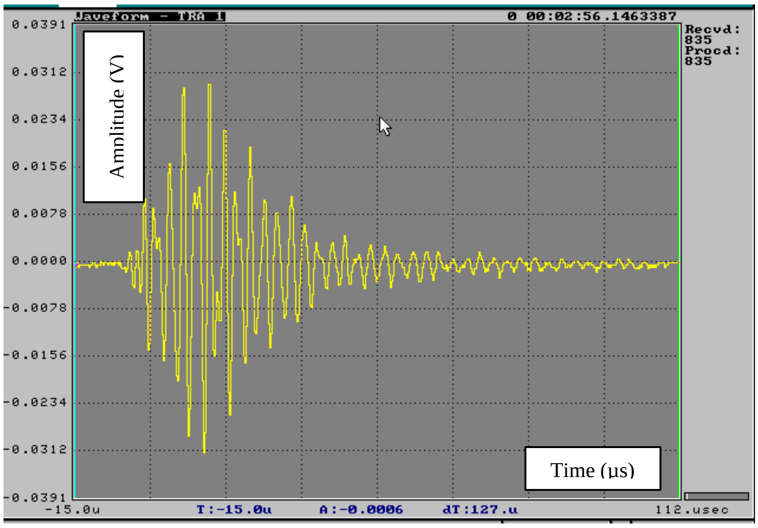


Fig. 2: Acoustic emission Waveform.

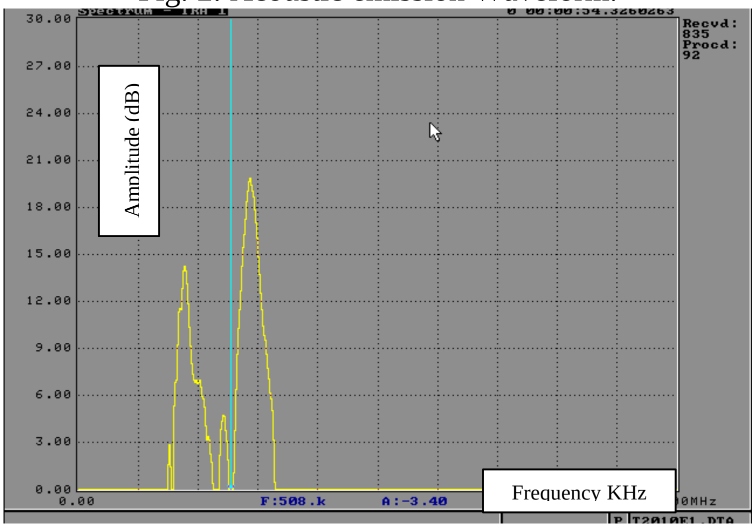


Fig. 3: Acoustic emission frequency spectrum.

In the case of used material and present experimental conditions the following values of the timing parameters were selected for doing the tensile test:

PDT = 40 µs, HDT = 80 µs and HLT = 200 µs

From the acoustic waveform different acoustics parameters are measured and analysed to identify damages mechanics in composite materials. Many works concerning different composites with different fibres and resins [3,4,5,6] have confirmed that the acoustic emission amplitude ranges correspond to different damage mechanisms, figure 5.

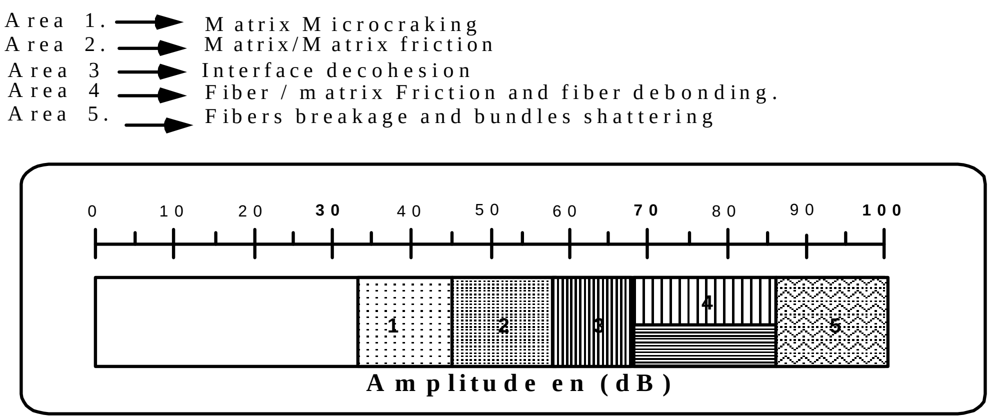


Fig. 4: Typical Amplitude Distribution and Areas definition

The damage growth detection and monitoring have been performed using the amplitude analysis of Acoustic Emission signals generated during the advent of damage and failure mechanisms. In addition of this parameter use of the energy and duration distribution will allows a better comprehension and thus the best followed mechanisms. Figure 5, shows the 3D distribution of AE amplitude.

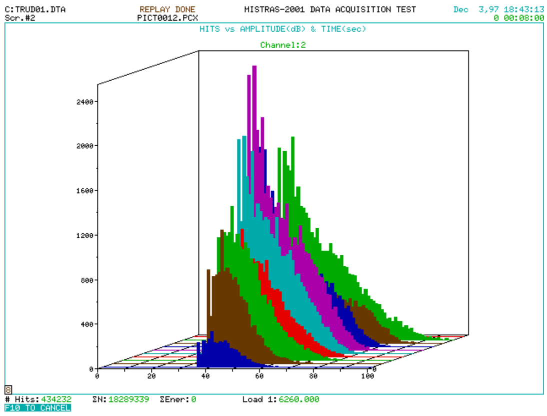


Fig. 5: Three-dimensional distribution of acoustic emission EA amplitude.

In order to determine the correspondence between the three parameters amplitude, energy and duration we carried out a graphic filtering. This graphic filter makes it possible to visualise on graphic the values of energies and the duration depending on range of chosen amplitude. Indeed in the first part are selected energy and the duration related to the amplitudes between 40 and 50 dB mainly due to the resin crack. Figure 6, present the top-view of amplitude distribution of acoustic emission filtered between 40 ad 50 dB.

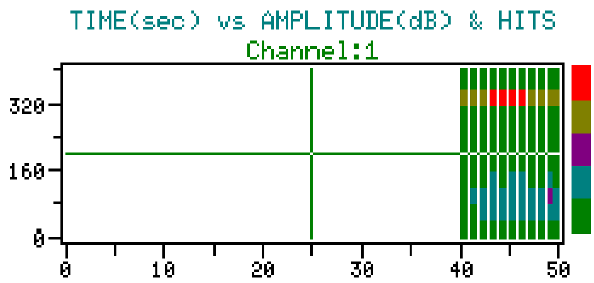


Fig. 6: Top-view of Three-dimensional distribution of amplitude between 40 and 50 dB.

This filtering give the following distributions of absolute energy and duration (figure7).

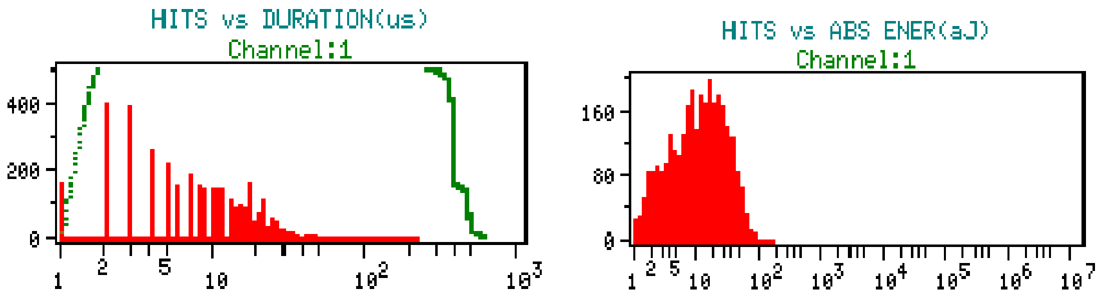


Fig. 7: Distribution of duration and absolute energy linked to 40 and 50 dB amplitude.

Between 40 and 50 dB the events have a weak energies comprised between 1 and 100 aJ (atto joule) and duration comprised between 10 and 100 µs. In this case the hit are characterised by a low amplitude and a fast attenuation of the signal. Same analyses are done for different range of acoustic amplitude (50-60 dB, 60-80 dB and 80-100 dB). This approach highlights the interactions that there were between the sorting acoustics parameters (amplitude, energy and duration). In the last part are selected energy and the duration related to the amplitudes between 80 and 100 dB mainly due to the fiber failure (figure 8 and 9).

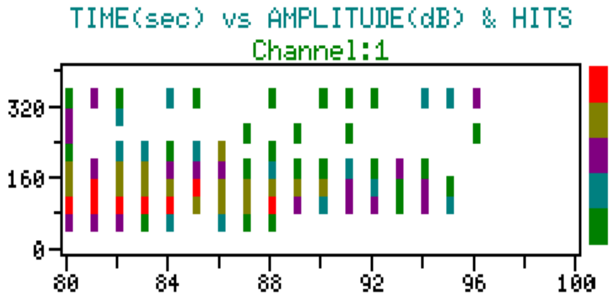


Fig. 8: Top-view of Three-dimensional distribution of amplitude between 80 at 100 dB.

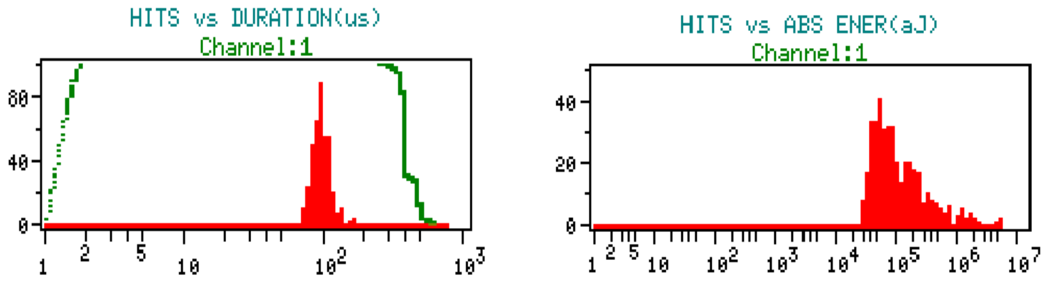


Fig. 9: Distribution of duration and absolute energy linked to 80 at 100 dB amplitude.

Preceding figures shows clear manner that strong amplitude event are characterised by significant duration and of strong energy. These events are mainly related to the fibre failure and with the macro final failure of the sample or of the composite structure. In the figure 10 are presented a multiparametric analysis which permit to visualise and to follow in real-time the three acoustic parameters and the damage of composite materials.

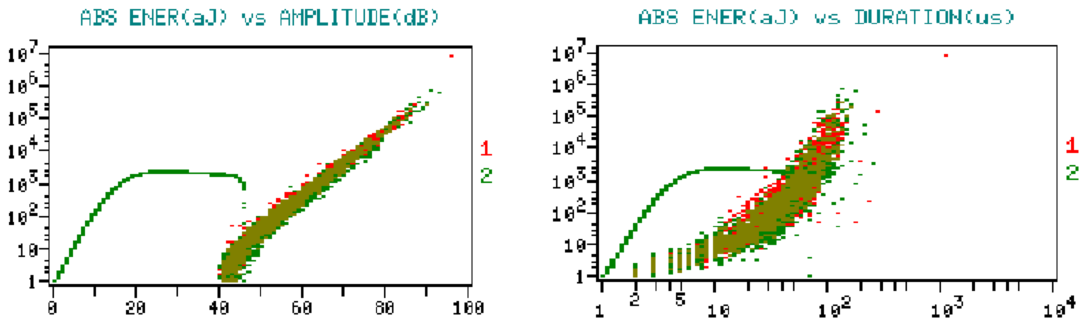


Fig. 10:Correlation between energy-amplitude and duration and amplitude of AE.

Tensile test analysis

In this study the goal of the tensile tests is to determine the influence of the structural parameters on the elastic behaviour, damage and failure of materials. The following figures illustrate the behaviour difference between the two materials where the only parameter which exchange is the quality of the interface.

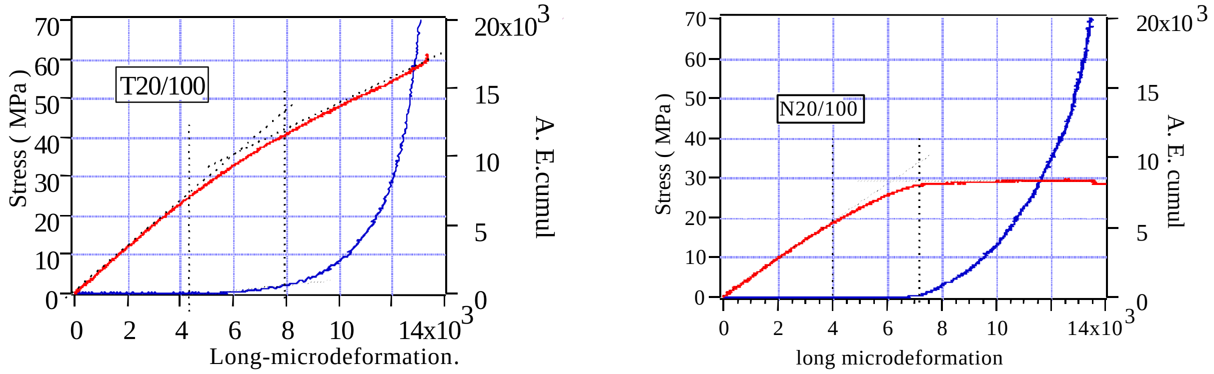


Fig. 11: Stress-strain and cumulative of acoustic evolution. T20/100andN20/100 material.

Indeed, a significant difference in mechanical behaviour is observed between the curve Stress-Strain in figure 11 correspondent to the T20/100 material where the quality of the interface is improved by the addition of an oiling and the curve correspondent to the N20/100 sample, with poor quality of matrix/fibre interface. In the case of T20/100 material, three significant phases on the curve are observed :

A first linear elastic phase. A second non-linear phase related to beginning of damage mechanics. In the start of this phase, the appearance of the first events of acoustic emission generated are observed. The third phase is characterised by a break of slope of the stress-strain curve. This change is accompanied by a strong acoustic emission. An exponential evolution is observed on the latter of cumulate curve indicating a strong damage leading to the final failure of material.

In the case of the N20/100 material, the behaviour is characterised by three phases different from the preceding case. A first linear elastic phase which permit to measure the elastic properties of material. A second non-linear phase, where no acoustic emission is detected. This phase relate a plastic deformation without damages. At the end of this part, appears the third phase where the stress-strain curve reach to a creep plate where the deformation grow under constant stress. This phase is characterised by a strong acoustic emission activity. This creep plate indicate the absence of load transfer between the matrix and glass fibre beyond the elastic field. The table below present the elastic constant and failures characteristics with a comparison between the two types of interfaces.

Taleau 2. Results of tensile test on composite materials with bad and good interface.

	T° mould 100°C		T° mould 100°C		T° mould 35°C	
Glass fibres Content	20 %		30 %		20 %	
Fibres Type	treated	untreated	treated	untreated	treated	untreated
E (GPa)	5,15 (0,30)	5,43 (0,49)	6,81 (0,41)	6,88 (0,64)	5,58 (0,15)	5,00 (0,23)
σ_f (MPa)	62,87 (6,73)	33,09 (1,90)	70,46 (3,67)	32,70 (1,07)	73,35 (4,23)	32,83 (1,01)
ε_f (MPa)	1,56 (0,36)	1,33 (0,25)	1,53 (0,25)	1,20 (0,60)	1,67 (0,63)	2,23 (0,25)

E = Elastic Modulus, σ_r = Failure stress, ε_r = Failure strain.

The oiling of fibres permit to double the failure stress of composite material. On the other hand the elastic modulus is not affected by this parameter. In both cases (treated fibres and untreated fibres), the acoustic emission (E.A.) characterise the appearance and the evolution of the damage after a quiet zone corresponding to the elastic phase [7,8].

Analysis of the damage

Within the framework of the damage mechanisms analysis, a continuous correlation is established between the acoustic emission and the microscope observations. The amplitude distribution has the advantage to affect the events according to their amplitudes and to classify it according to their damage ranges. It also makes possible to follow damage chronological way during the loading. Figures 12 present the distributions of amplitude obtained for sample loaded in tensile test, with oiled and not oiled fibres/matrix interface.

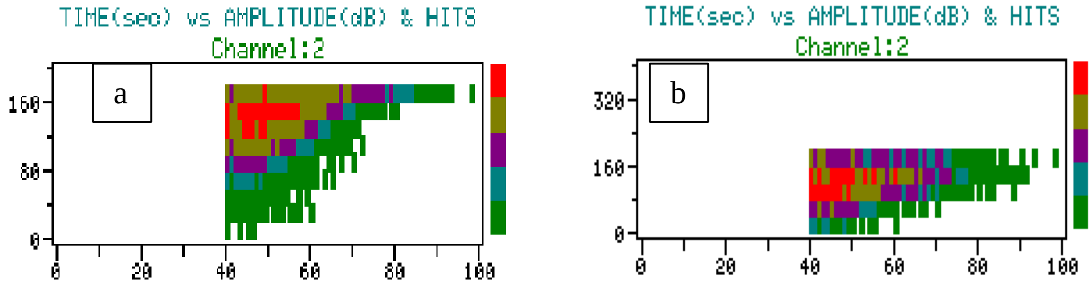


Fig. 12: Amplitudes distribution a) T20/100 and b) N20/100 material, for various time.

The evolution of amplitude distributions show that the total number of recorded events coming from the oiled fibres case is more significant than the not oiled fibres case. In the same way, the events number decrease when the fibres rate increases. This notice is valid in both cases (oiled fibres and not oiled fibres).

In the case of oiled fibres, the amplitude distribution is less broad (figure 12a). The evolution of the damages is weaker between 60 and 80 dB, recording to less matrix/fibres interface failure and fibre and pullout of fibres. Therefore a better adherence matrix/fibres give consequently a better mechanical behaviours. At the end of the test, the failures of fibres are observed through acoustic amplitude between 80 and 100 dB.

Figure 12b, shows that in the case of not oiled fibres, the amplitude distributions are very spread out what testifies to the several damage presence types (matrix cracking, microscopic cracks coalescence, interfaces failure, matrix/fibres friction and failure fibres). That is noticed more especially when the rate fibres is less.

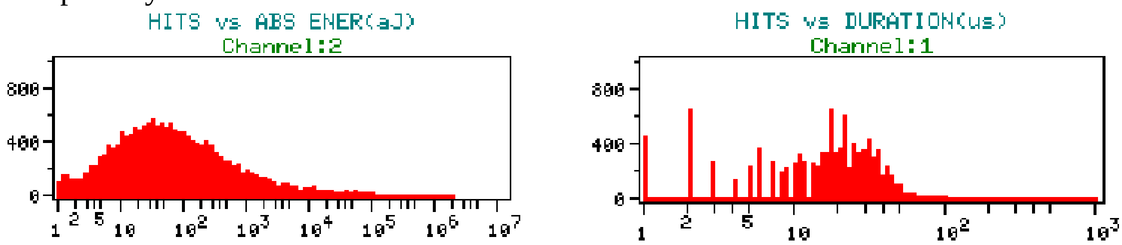


Fig. 13: Energy and duration distribution in tensile test of the T20/100 material.

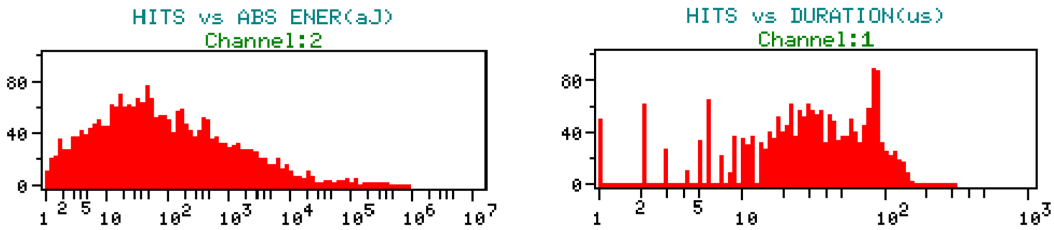
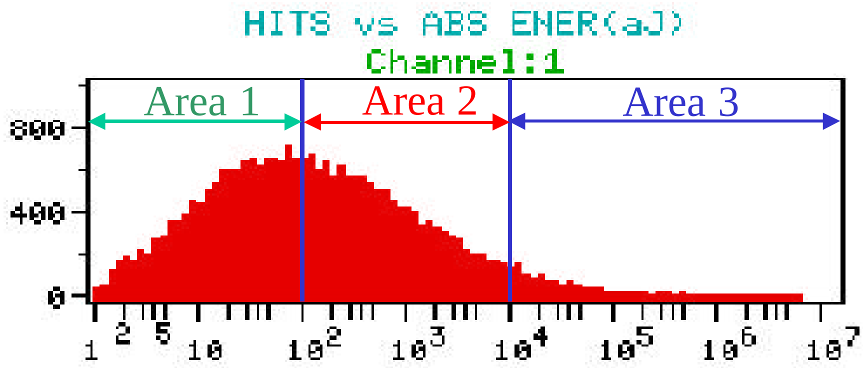


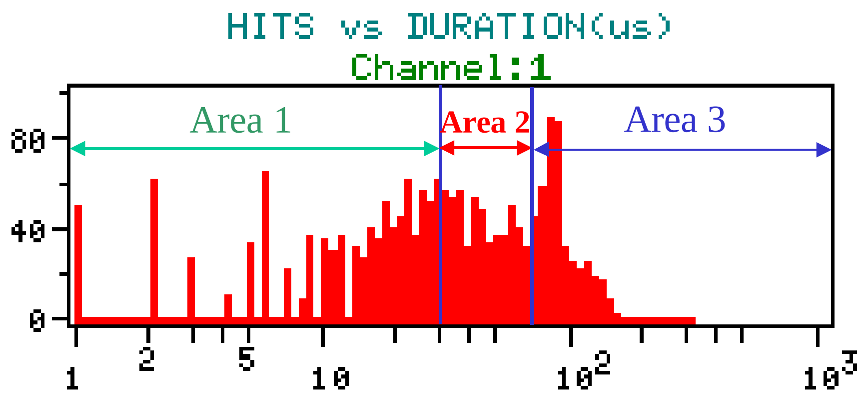
Fig. 14: Energy and duration distribution in tensile test of the N20/100 material.

Through the energy distribution, a different behaviour are observed according to material and the type of fibre/matrix interface. In the case of the oiled composites the relatively significant presence of events between (10^3 and 10^4 aJ) comes mainly from interface failure phenomena and pullout of fibres. Duration curve shows the same phenomena through an events having duration around 100 µs due to the same mechanisms (interface failure). The events with more significant duration (>500) are generally due to very energetic mechanisms such as fibres failure and delamination. Having regard to below result two models are proposed for making it possible to correlate damage mechanisms to the two acoustic parameters (energy and duration) figure 15 and 16.



Area 1 = Matrix Microcraking and Matrix /Matrix friction
Area 2 = Interface decohesion and Fiber / matrix Friction
Area 3 = Fibers breakage and bundles shattering

Fig. 15: Typical Model of Energy Distribution and Areas Definition.



Area 1 = Matrix Microcraking and Matrix/Matrix friction
Area 2 = Interface decohesion and Fiber / matrix Friction
Area 3 = Fibers breakage and bundles shattering

Fig. 16: Typical Model of duration Distribution and Areas Definition.

Presented models obtained from the study materials will be confirmed on other composites materials subjected to different type of loading. The range precision of the various distributions must be refine for a better precision during the results analysis. By using the amplitude distribution histogram with the energy and duration distribution which correlated to load history, damage initiation and progression during static and quasi-static tensile loading could be clearly established. In the future analysis of waveform correlated to this type of approach will permit to extrapolate these results on more complicated geometric structures [9]

Conclusion

This study produced a number of important results for the understanding of both the analysis of acoustic emission signals from composites damage as matrix microcraking, matrix/matrix friction, interface decohesion, fibre / matrix friction and fibre breakage. By using the amplitude, the energy and duration distribution histogram, which correlated to the load history, damage initiation and progression during tensile loading could be clearly established. This allows to propose two graphic acoustic models based on energy and duration distribution histogram.
These models following by a mechanical characterisation made it possible to highlight the effect of structural parameter (fibre/matrix interface) on the mechanical behaviour of a composite material with short fibres and thermoplastic polypropylene matrix loaded in tensile test. The obtained models will be confirmed and refined, in other conditions, for a better accuracy during the results analysis.

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