DAMAGE LOCALIZATION IN DESIGNED FAILURE COMPOSITES

G. Szebényi[1,2,3], G. Zs. Marton[1,2], G. Romhány[1]

[1]Department of Polymer Engineering, Budapest University of Technology and Economics, Műegyetem rkp. 3., H-1111 Budapest, Hungary
[2]MTA-BME Lendület Sustainable Polymers Research Group, Műegyetem rkp. 3., H-1111 Budapest, Hungary
[3]MTA-BME Lendület Lightweight Polymer Composites Research Group, Műegyetem rkp. 3., H-1111 Budapest, Hungary
Email: szebenyi@pt.bme.hu
Email: martong@pt.bme.hu
Email: romhany@pt.bme.hu

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Abstract

The failure of composites is a complex process, mostly caused by different damage mechanisms and their interactions. In order to validate methods used for influencing and controlling the failure process, it is inevitable to detect the different damage mechanisms and get a better understanding of them. In our research, we have used specific tests on the composite and its constituents to provide characteristic AE data for the proper description of AE events related to damage modes inside the composite (fibre fracture, fibre-matrix debonding, matrix cracking, delamination). The collected and analyzed data can help with the monitoring of the failure process in designed failure composites.

1. Introduction

Polymer composites contain a large number of local damages, which can be explained by, among other factors, their heterogeneous microstructure, the significant differences between the properties of the reinforcing material and the matrix, the presence of interfaces and the anisotropic properties of the composites, all of which contribute to the complexity of their damage and failure mechanisms. Damage can be diverse and can be classified according to several criteria, e.g. source, typical size range. However, in general we can distuingish four basic modes of damage: fibre fracture, fibre-matrix debonding, matrix cracking, delamination [1, 2].

Detection of damage and determination of the residual mechanical properties are essential for the application of composites in safety-critical components. However, it often proves to be a challenging task. NDT methods can be used to provide structural health monitoring of composite structures, which contributes to increasing their reliability, and to detect subcritical defects of the structure, which simplifies the planning and execution of maintenance processes. Several methods are used for non-destructive testing of composites. The advantages and disadvantages of each method must be taken into account when selecting the appropriate NDT procedure. In order to eliminate the disadvantages, the different methods are often combined. [3, 4].

Acoustic emission (AE) method is a widely used NDT technique in the field of composite materials. AE is one of the acoustic wave-based methods, where the investigation of the acoustic waves generated by the energy released as a result of the damage mechanisms enable the localisation of the damage and the determination of the mode of the damage based on the time difference of arrival and signal properties, e.g., amplitude, energy, frequency [4-7].

In our research, we carried out specific tests to induce different damage mechamisms and analyzed the data collected by AE to get a proper description of the damage modes.

2. Materials and methods

2.1. Materials

We used IPOX MR 3010 (IPOX Chemicals Kft., Budapest, Hungary) epoxy resin (EP) with IPOX MH 3124 amin type curing agent as matrix material of the composite specimens as well as for the resin probes and the microbond tests. The components were mixed in a weight ratio of 100:35. We applied PX35FBUD0300 (Zoltek Zrt., Nyergesújfalu, Hungary) stitch-bonded unidirectional carbon fabric (309 g/m2 surface weight), consisting of Panex35 50k rovings as reinforcement material for the composite specimens. Elementar fibers for the microbond tests and the single fiber tensile tests were taken from these rovings as well.

2.2. Sample production

We manufactured composite plates with [$0°_6$] layup sequence by vacuum-infusion. From the plates specimens (with 2.5 mm nominal thickness) according to ISO 1430 standard were cut for the short-beam shear tests with a Mutronic Diadisc (Mutronic, Rieden am Forggensee, Germany) diamond disc cutter. Specimens according to ISO 527-2 standard were cast from epoxy in silicon moulds. Fibers for single fiber tensile test and microbond test were prepared from the carbon rovings on a paper frame providing 25 mm fiber length. For the latter, a microdroplet of epoxy was placed onto each fiber.

2.3. Methods

The tensile testing of the epoxy specimens was carried out according to the ISO 527-2 standard with 5 mm/s test speed using a Zwick Z005 (Zwick GmbH, Ulm, Germany) universal testing machine with a 5 kN load cell. Single fiber tensile tests and microbond tests were conducted on a Zwick Z005 (Zwick GmbH, Ulm, Germany) universal testing machine with a 20 N load cell and 0.5 mm/min test speed. For the microbond tests, a microbond device fixed on the tensile tester was applied. The device contains two steel blades which are responsible for supporting the droplet during the debonding process and their position can be set with micrometers. Olympus BX51M (Olympus Corporation, Tokyo, Japan) optical microscope was used for determining the geometrical data related to the droplet. We carried out the short-beam shear (SBS) tests according to ISO 14130 standard using a Zwick Z020 (Zwick GmbH, Ulm, Germany) universal testing machine with a 20 kN load cell. For the SBS tests, we applied 12.5 mm span and 5 mm/min test speed.

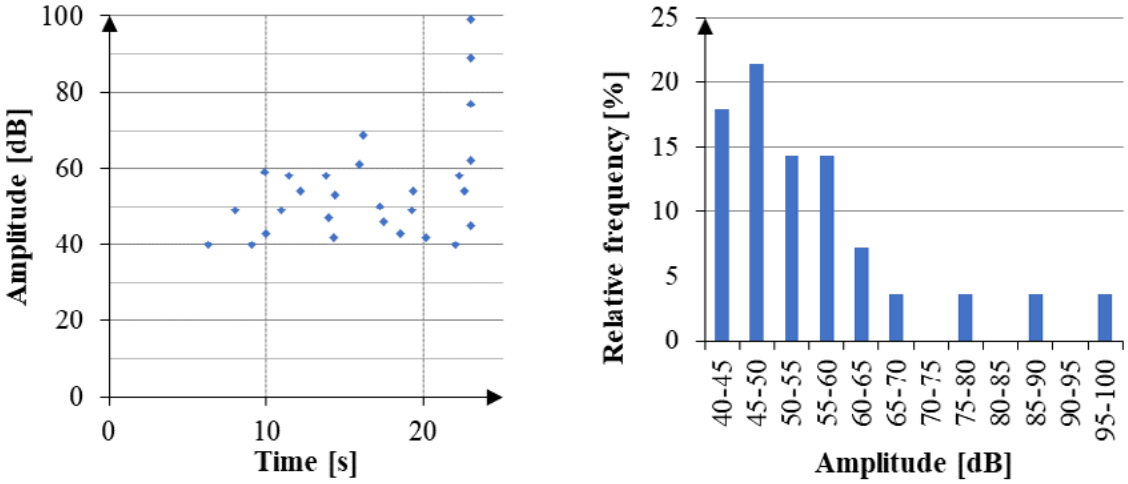
The acoustic emission testing was carried out with a Mistras PCI-2 (MISTRAS Group, Princeton Junction, USA) AE system. We used an IL40S preamplifier (Physical Acoustic Corporation, Princeton Junction, USA) with a gain of 40 dB and a Micros30s (Physical Acoustic Corporation, Princeton Junction, USA) microphone (operating frequency range: 150–400 kHz). The microphone was connected two the specimens with Oxett silicon grease (T-silox Ltd., Budapest, Hungary) coupling agent. The threshold for the measeurements was 30 dB.

3. Results and discussion

While analyzing the AE data of the different measurements, we focused on three properties of the AE signals: amplitude, average frequency and signal strength. Preliminary tests showed that the signals from crosshead movement and friction resulted in signals above the 30 dB threshold, so during the analysis of the data, signals with an amplitude under 40 dB were characterized as noise.

3.1. Tensile testing of epoxy

From the AE data acquired during the tensile testing of epoxy specimens, we determined the properties of AE signal characteristic of matrix cracking. Typical data related to the amplitude of AE signals of an epoxy specimen is shown in Figure 1. The results show that a few high-amplitude signal are only recorded directly at the global failure of the specimen. The signals related to matrix cracks are typically in the 40-60 dB amplitude interval.



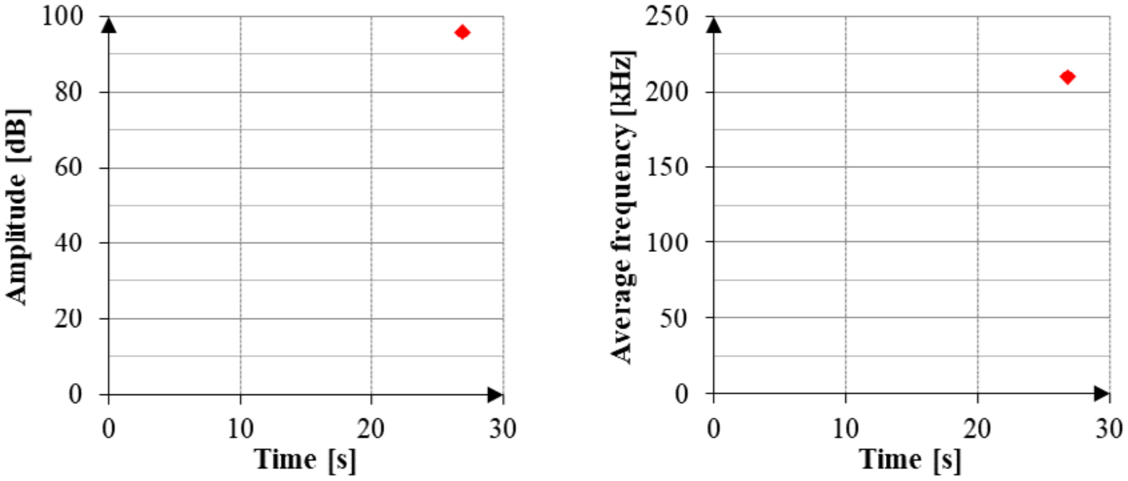
a) b)

Figure 1. Typical data for an epoxy specimen a) amplitude-time and b) amplitude distribution diagram

The analyzed data suggests that in case of average frequency the signals are mainly in the 100-150 kHz interval, while for signal strength, the 0-10 000 aJ interval is typical.

3.2. Single fiber tensile tests

In the case of single fiber tensile tests, the measurement resulted in one acquired AE signal (Figure 2). Based on the measured data, the 80-100 dB amplitude and the 200-275 kHz average frequency interval are characteristic of the applied carbon fiber's failure.



a) b)

Figure 2. Typical data for a single fiber tensile test a) amplitude-time and b) average frequency-time diagram

In the case of signal strength, the data varied in a wide range between 180 000 and 700 000 aJ.

3.3. Microbond tests

The acquired AE data for each microbond test consists of few signals, where the first signal with high amplitude is associated with the fiber-matrix debonding process, while the further signals with lower amplitude levels can be explained with friction between the fiber and the matrix droplet (Figure 3).

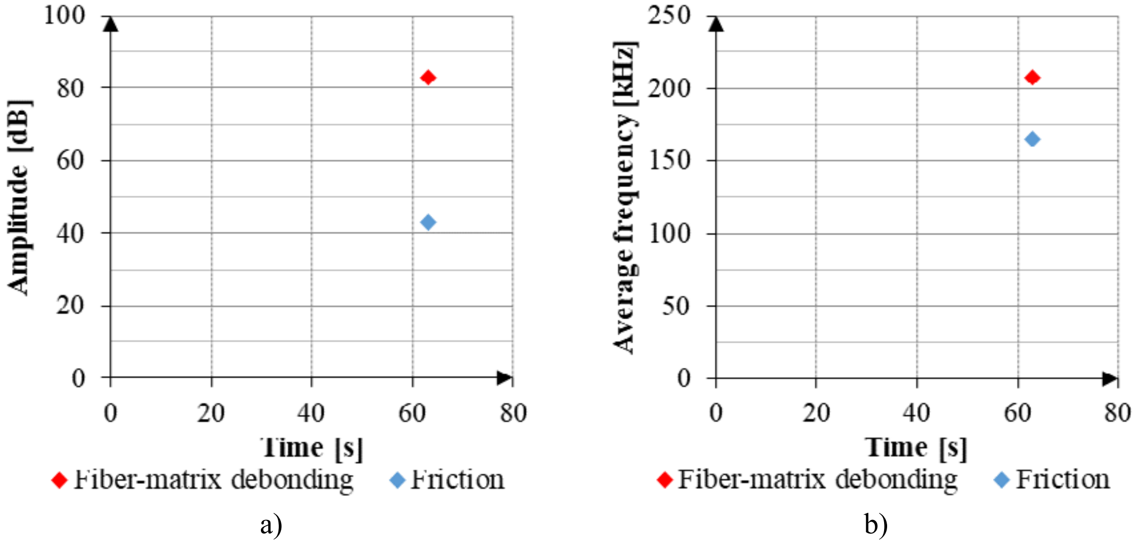


Figure 3. Typical data for a microbond test a) amplitude-time and b) average frequency-time diagram

The results show that fiber-matrix debonding can be associated with signals in the 70-85 dB amplitude, 160-210 kHz average frequency and 200 000-600 000 aJ signal strength ranges.

3.2. Short-beam shear tests

Typical data related to the amplitude of AE signals acquired while conducting the short-beam shear test of a UD carbon fiber/epoxy composite specimen can be seen in Figure 4.

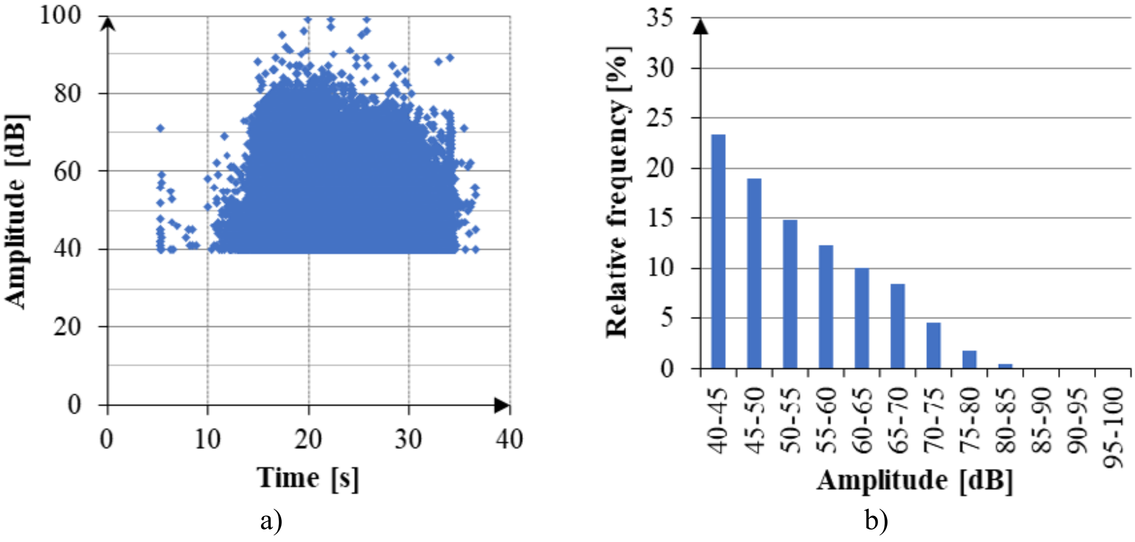


Figure 4. Typical data for a short-beam shear test a) amplitude-time and b) amplitude distribution diagram

It is important that Figure 4 shows raw AE data. However, for the short-beam shear test - besides the delamination we wanted to characterize - matrix cracking is a typical damage mode as well. In order to eliminate the signals acquired from matrix cracking, we filtered the data according to the properties determined for matrix cracking with the tensile testing of epoxy specimens.

The results suggest that 60-80 dB amplitude, 125-225 kHz average frequency and 35 000- 200 000 aJ signal strength intervals are the characterictic ranges for the AE signals induced by delamination process.

4. Conclusions

In our research, we induced the four basic damage modes of composites separately by applying specific test methods. During the tests, we collected data related to damage process by AE method. By analyzing the measured data, we determined the properties of the characteristic data of the different damage modes. The results will be used in our further research to characterize the formation of damage inside the structure of designed failure composites.

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