Acoustic emission monitoring of composite specimens with impact damage during static compression test

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Abstract. The standard specimens have been made by anisotropic carbon fiber plastic with an epoxy matrix. The specimens were subject to static load after its shock impact. During static compression loading, the parameters of acoustic emission (AE) signals were synchronously recorded: AE impulse amplitudes, its energy and the number of oscillations. According to the analysis of the acoustic emission signals the following events were observed: matrix cracking, fiber delamination and fiber destruction. The character of the AE signals change made it possible to determine the energy of the acoustic emission signals as a diagnostic witness of the onset of two moments of the specimen destruction. The first = near 70% of ultimate load’s (the destruction of matrix) and total destruction under ultimate static load.

Keywords: acoustic emission, composite materials, impact damage, compression test

1. Introduction

This test method covers compression residual strength properties of multidirectional polymer matrix composite laminated plates, which have been subjected to drop-weight impact per test method ASTM D7136 [1] prior to application of compressive force. After impact damage specimens were tested on compression test ASTM D7137 with acoustic emission (AE) signals synchronously recorded. The method utilizes a flat, rectangular composite plate, previously subjected to a damaging event, which is tested under compressive loading using a stabilization fixture [2].
Figure 1. Schematic of compressive residual strength support fixture with specimen in place and AE sensors

2. Experimental

Specimens were made of carbon fiber HexPly M21 it is a high performance, very tough epoxy matrix for use in primary aerospace structures [3]. It exhibits excellent resistance to damage, especially at high energy impacts. HexPly M21 is a toughened epoxy resin system supplied with unidirectional woven carbon. In total were tested 5 specimens. General view of specimen and testing rig are shown on Fig.2. The compressive test fixture, shown in Fig. 1 and Fig. 2, utilizes adjustable retention plates to support the specimen edges and inhibit buckling when the specimen is end-loaded. The fixture consists of one base plate, two base slide plates, two angles, four side plates, one top plate, and two top slide plates.

Figure 2. General view of testing rig and specimen with AE sensors support glued

Specimens have dimensions of 150 mm length x 100 mm width and a thickness of 3 mm. In total four AE sensors used. Vallen system AMSY-6 is a digital multi-channel acoustic emission (AE) acquisition system to obtain AE energy and amplitude signals during loading. A measurement channel consists of an AE sensor, preamplifier and one channel of an ASIP-2 (dual channel acoustic signal processor). Each channel combines an analogue measurement section and a digital signal processing unit. AE features, such as time of the first threshold crossing (arrival time), rise time, duration, peak amplitude, energy and counts, are extracted by the ASIP-2 [4]. According to the procedure, the
calibration was performed using a standardized source of Hsu-Nielsen (Hsu-Nielsen source). In this case, the threshold value was 30.1 dB [5].

The AMSY-6 provides 4 types of measurement data:

- Hit data: data that is generated when the AE signal exceeds the threshold.
- Status data: data that is generated in regular time intervals
- Parametric data: data of external parametric sensors which are measured at regular time intervals. Parametric data is stored with every hit and at user-specified time intervals.
- Waveform data: sampled AE sensor signal

The Instron 8801 machine have been used for specimen compressive loading. The Instron 8801 100 kN is a compact servo hydraulic fatigue testing system that meets the challenging demands of various static and dynamic testing requirements. 8801 systems provide complete testing solutions to satisfy the needs of advanced materials and component testing, and are ideally suited for fatigue testing and fracture mechanics [6].

Instron 9400 series is a drop tower test system that performs mono-multi axial impact tests on products and specimens. The system allows to set impact energies ranging from 0.3 to 405J, allowing to test a wide range of products and materials, also thanks to the large volume of work available for the positioning of the sample. Specimens of carbon fiber HexPly M21 were damaged with 25J impact. After damage specimen is installed in a multi-piece support fixture (Fig.2), that has been aligned to minimize loading eccentricities and induced specimen bending. The specimen assembly is placed between flat platens and end-loaded under compressive force until failure. Applied force, crosshead displacement, and AE energy and amplitude data are recorded while loading.

3. Result and discussion

Analysis of the results of changes in the energy of acoustic emission signals for the specimens and their location showed that AE location practically does not affect the general nature of the change in the AE signal energy. Nevertheless, the location of the AE sensor at position 4 most characteristically showed a three-stage process of sample destruction. Considering the general structure of the composite material (Fig. 3), it can be noted:

1. Protection cover destruction,
2. Boundary sheetmatrices destruction,
3. Structural significant items (SSI) destruction.

Figure 3. View of specimen structure
Figure 4. Acoustic energy signals of 1-2 sensors measured on specimen 1

Figure 5. Acoustic energy signals of 3-4 sensors measured on specimen 1

Figure 6. Acoustic energy signals of 1-2 sensors measured on specimen 2
Figure 7. Acoustic energy signals of 3-4 sensors measured on specimen 2

Figure 8. Acoustic energy signals of 1-2 sensors measured on specimen 3

Figure 9. Acoustic energy signals of 3-4 sensors measured on specimen 3
Figure 10. Acoustic energy signals of 1-2 sensors measured on specimen 4

Figure 11. Acoustic energy signals of 3-4 sensors measured on specimen 4

Figure 12. Acoustic energy signals of 1-2 sensors measured on specimen 5
Determining the destruction of the composite material with AE signals it is obvious that the onset of destruction will begin with auxiliary components the initial, first stage, recorded by low-power AE signals. Further, the process of destruction affects SSI by about 70% of the load and the third, final stage, a final loss of the bearing capacity is observed, accompanied by the final destruction of the sample occurs by the release of energy recorded by the AE sensors.

Thus, it becomes possible to predict the destruction process of the specimen at the moment of the onset of the second stage of its destruction. A similar picture is observed in the analysis of changes in the acoustic emission energy signals for 5 specimens. The most typical view of three zones destructions we can see on specimen №3 (Fig. 8 and Fig. 9).

The energy is given in energy units (eu) and the software takes the selected gain into account, when calculating and displaying the energy. Energy is calculated by squaring the digitized AE signal and integrating the results during the hit. 1 eu corresponds to 10^-14V^2 sec at the sensor output. The energy is processed in either a so-called true energy mode, or a signal strength mode. In both modes, the energy is given in energy units (eu) and the software takes the selected gain into account, when calculating and displaying the energy. The energy is stored in a logarithm format with a resolution of 0.1%. Application of AE signals as a diagnostic feature for on-line monitoring for working with Helicopter health and usage monitoring (HUMS) and Structural Health Monitoring (SHM) systems.[7-9]

Conclusion

Analysis of the results of the acoustic emission signals recorded by the energy sensors under static loading before the destruction of the composite samples allows us to do the following conclusions:

1) The process of destruction of composite specimens includes three stages:

- Stage initial, accompanied by the destruction of non-force elements of the composite material approximately up to 20% of the destruction load;
- Stage of the beginning of the destruction of auxiliary SSI, approximately up to 70% breaking load without loss of bearing bearing capacity;
- Stage of the final destruction of the specimen, with a breaking load (100%), accompanied by a complete loss of bearing capacity.
2) The presence of several stages of destruction of the composite material allows using the second stage of destruction of SSI as a diagnostic sign of the onset of destruction failure of SSI and its use in monitoring systems for the technical condition of SSI, such as Structural Health Monitoring (SHM) and Health and Usage Monitoring System (HUMS).

3) The stages of destruction of composite materials and the ability to control their destruction by acoustic emission methods allows designers to design SSI on the principles of safe destruction of structures (Fail-Safe Concept).

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