Acoustic Emission testing to evaluate a new parameter in composite materials: Delay cracking Load

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Abstract
The aim of this paper is to investigate a new parameter in the behavior of carbon-epoxy composite materials: “Delay Cracking Load (DCL)”. The delay cracking load is a constant load that applied at a three point flexural bending test give up to a delay cracking process up to the complete fracture in composite specimens. Only Acoustic Emission technique is able to predict the delay cracking in constant load. DCL is an important parameter in the characterization of the composite materials. The interval between the load steps based on this research shall not be less than 2-5 days.

Keywords: delay crack load, Acoustic emissions, Carbon-epoxy composite, fracture mechanisms.

1. Introduction

Carbon fiber composites [1, 2] in the early 60s were used because of high strength and stiffness coupled with low weight and high resistance to corrosion and fatigue compared with traditional materials such as metals (see figure 1). Carbon fibers are a new generation of high strength fibers that used in composites with light weight matrix such resins. For this reason Fiber composites are suitable to make aircraft parts (Fig 2).

Till today, knowledge about plastic materials failure limit is more complex than for linear elastic materials like metals. Plastics can be dimensioned by means of critical strain as failure limit. So, acoustic emission method is a valuable analysis in a tensile test, to get quick value of critical strain of a new material [3].

Interface fracture is one of the critical failure modes for composite structures, which may lead to the separation of plies and eventually to the fault of the component: it is therefore necessary to strengthen the interlaminar fracture toughness for highly reliable composite materials and structures. Knowledge about the fracture mechanisms is vitally important in different kinds of loading test. As some of the authors have already demonstrated, interleaving small diameter
fibers between one or more interfaces, improves strength, toughness and delamination resistance of composites without reducing in the in-plane properties or adding weight [4-9].

For composite materials design, knowledge of fracture mechanisms is vitally important, so AE is one of the suitable techniques to investigate the online fracture mechanisms [5, 10-14]. The most important advantages of AE is on-line monitoring for fracture or friction between the layers or fibers and the capability to detection of the damage mechanisms [15]. Most common analyzing method for AE, uses certain features extracted from signals such as amplitude, energy, count, rise time [16].

![Figure 1. Benefits of using composite materials](image1)

The successful development and design of continues fiber reinforced carbon epoxy composites are dependent on a thorough understanding of basic properties such as fracture and delay failure, slow crack growth or damage accumulation[17].

2. Materials and Methods

2.1. Composite fabrications

Panels were fabricated by hand lay-up process, after the lay-up, panels were cured by vacuum
bag in an autoclave in 185°C (365 °F) according to process specification provided by supplier. Carbon unidirectional preprag fiber-epoxy composite (table 1) were used in constant load to investigate the delay crack in carbon epoxy composite in sequence loading (Fig 3).

Table 1: unidirectional 0/90 preprag of carbon epoxy composite

<table>
<thead>
<tr>
<th>Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of resin</td>
<td>33%</td>
</tr>
<tr>
<td>Percentage of fibers</td>
<td>67%</td>
</tr>
<tr>
<td>Preprage (weight per unit area)</td>
<td>134 g/m²</td>
</tr>
<tr>
<td>Fiber type</td>
<td>Unidirectional carbon fibers 0°/90°</td>
</tr>
</tbody>
</table>

2.2. Mechanical flexural bending testing

The three point flexural bending test has appointed to perform flexural test for the characterization of composite materials and two AE sensors have been applied on the specimens (Fig 4).

Mechanical hydraulic test has been set up to minimize the noise level on the acoustic emission system during the step loading on the specimens.

The flexural test has been calculated according to the ASTM D790[18]:

AE features such as count, rise time, energy and amplitude,

\[
\sigma_f = \frac{3PL}{2bd^2}
\]

(1)

\(\sigma_f\): Stress in the outer fibers at midpoint, MPa (psi).

P: load at a given point on the load-deflection curve, N (Newton).

L: support spans (mm).

b: width of beam tested (mm) and,

d: depth of beam tested (mm).

Fig 4: (A) Three-Point bending flexural test by AE, (B) Three-points bending test on carbon epoxy composite through silent hydraulic pressurized
2.3. Acoustic emission equipment

The AMSY-6 acoustic emission system\(^1\) was used for damage monitoring during monotonic 3-point bending examination of composites in mechanical hydraulic test. The AMSY-6 was equipped with Vallen software for data acquisition and analysis. Loading data were transferred directly to AMSY-6 system allowing for correlation with acoustic signals obtained from examined GFRP and CFRP specimens. The AE signals were registered using two broad-band sensors attached to specimen’s surface with rubber band and vacuum grease as a coupling agent (Fig 4B). The Vallen AEP4 preamplifiers had the gain set to 34 \(dB\). System threshold setting varied from 34 to 46 \(dB\). Sensitivity of the sensors and placement of the sensors was calibrated by Hsu-Nielsen source preceded the actual measurements.

After the calibration step, AE signals were recorded during the mechanical testing. Signal features such as count, rise time, energy and amplitude were used for investigating of the failure mechanisms (Fig 5).

![Figure 5](image-url) Amplitude vs. time presentation of AE signals during the delay cracking load. The first and second load applied before in the period of 7 days does not provoke any delay cracking.

3. Results and Discussion

In the Carbon epoxy specimens, the same procedure has been applied as for the glass-epoxy composites. The delay cracking load has been identified at the third applied load. This load has been kept constant for all the test duration. After 184 hours the first high amplitude clusters of

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\(^1\) Manufactured by VALLEN System GmbH, 82057 Icking, Germany. http://www.vallen.de/
AE signals representing the micro cracks in fiber and matrix (see Fig 5).

From 222 hours a scattered high amplitude signals ranging from (60-95 dB) appear in the monitor of AE. The pattern distribution of these signals was different from the glass epoxy composites, not in periodical cluster but in the “sky stars shape” signals. At the end time (264 hours) through the thickness surface breaking crack emerged in the specimens (see figure 5). The crack was along the axis of the high stressed area (figure 6). At the end stage SEM picture captured from the surface of fracture (Fig 7).

![Figure 6](image6.png)

**Figure. 6** Main surface breaking fracture appeared after continues process of delay cracking

![Figure 7](image7.png)

**Figure. 7** SEM from the fracture in carbon epoxy composite: (A),(C): matrix cracking and fiber breakage (B) fiber breakage (D) matrix cracking[19, 20]

### 4. Future work

The important of the phenomena of delay cracking load in the project and manufacturing composite materials speed up a research to correlate the final ration of strength data with the delay cracking load data.

Most probably this will have as a result more reliable composite material for the construction which are more and more complex and extended in the application.

The recent introduction of nanofibers (Fig 8) in composite material manufacture will give
ongoing research may give a contribution improving the mechanical properties of the composite materials [19, 20].

5. Conclusion

Delay cracking load is a new investigation in composite materials. In 3-point bending by apply the constant load for a long time, fracture mechanisms occur. Knowledge of the critical load is an important parameter to prevent delay crack loading. Acoustic Emission technique is a suitable method to detect the delay cracking load in composite materials. For the better indication of delay cracking load, attention to the amplitude of the signals, strongly provides. so the knowledge of critical constant load could help to prevent the failure mechanisms by the time in each composite material.

![Figure 14](image)

Figure 14 (a) nanofibers of nylon 6,6 (b) fracture mechanisms in Nano nylon 6,6 in carbon epoxy composite

Reference


