# Acoustic emission based damage analysis of pultruded glass fiber reinforced materials

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## Pultruded materials

Composite materials have good rigidity-to-weight and strength-to-weight ratios, thanks to the combination of properties of the matrix and the reinforcement. However most of the production means rely on manual steps and therefore is costly for an industrial product.
Pultrusion is an automated technological process to continuous production of product with constant section in composite materials. The terms derives from pull and extrusion, since the process include an extrusion process where the glass fibers are loaded with a tensile load that makes possible to correctly align the fibers before the matrix is polymerized (Figure 1). This process allows to manufacture complicated constant section profile without many of the problems involved in metallic extruded profiles. It's easily automatable in an industrial context, lowering the production costs. [1]

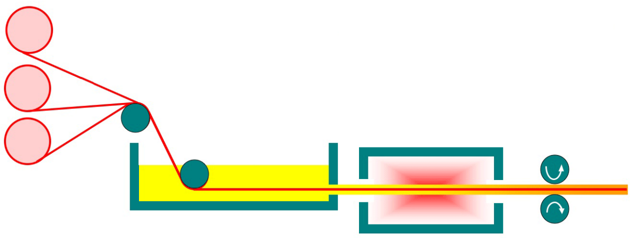

Figure 1: A schematic drawing of the pultrusion process.

These characteristics contributed to the extension of the field of use of these materials to civil structures (mainly bridges, sheds, anti-noise panels). However, the limited knowledge on fatigue and damage modes of these materials limit their applications (Figure 2), for example in aerospace structures, where light alloys (Aluminium above all) are still preferred for their more uniform and predictable behaviour. The testing conditions also greatly influence the experimental results. [2]

## Experimental study

To fill this gap, an experimental study has been developed. A traditional fatigue testing plan was set up to assess the damage modes of the material at different load levels. Each specimen was monitored through all the test with an acoustic emission (AE) monitoring system, recording and localizing signals.

## *Material*

The material used during the tests is a pultruded glass-fiber reinforced material consisting in a polyester matrix, an uniform E-glass fibre reinforcement and three layers of Mat (which consists of random oriented long glass-fiber), which should grant better mechanical characteristics in the directions normal to the fiber orientation (Figure 3). The section is rectangular, 6x30 mm, with the Mat placed at the two opposite faces of the rectangular section and in the middle.

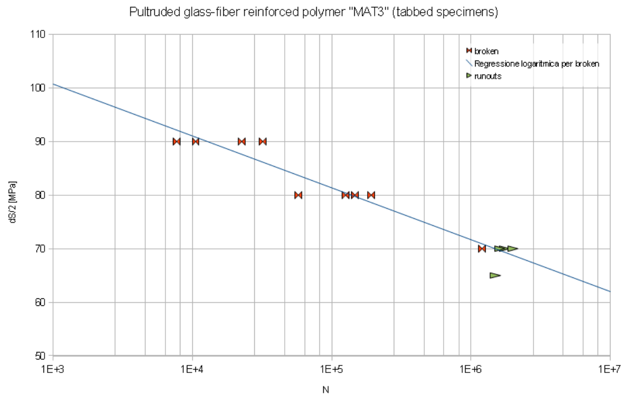


Figure 2: A typical Wohler diagram for a composite material, showing the high dispersion.

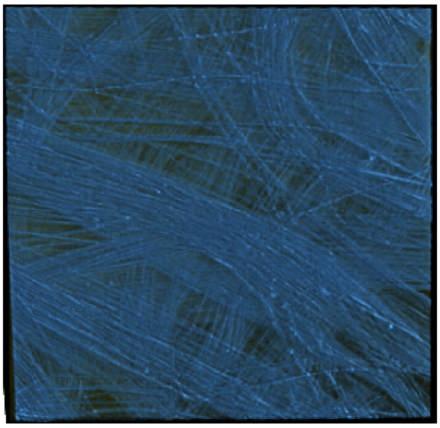

Figure 3: Tomographical image of Mat fiber structure.

## *Instrumentation*

AE instrumentation consists of a set of passive piezoelectric sensor, monitoring the acoustic emission of the material (which is related to the release of energy during damage and is typically in the ultrasonic band) [3]. In our study we used 2 sensors, at a fixed distance (Fig. 4). This type of setup allows to localize the events in the longitudinal axis of the specimens.

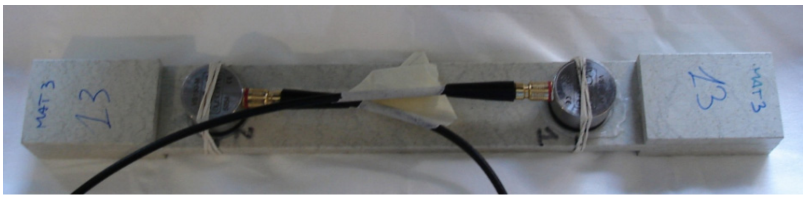


Figure 4: Specimen with 2 sensors mounted for linear localization.

The sensors are connected to an acquisition system which elaborates the signals and produces various outputs. A software allows the user to choose between various indicators, for example:

- ✓ counts (the number of times a given signal exceeds a fixed threshold);
- ✓ energy (the energy of an event);

- ✓ amplitude (the maximum amplitude of an AE event);
- ✓ risetime and duration (characteristic times of a signal).

Each signal can be displayed as a cumulative, by location, by time, or combined.

## ACOUSTIC EMISSION TESTING RESULTS

The specimens we tested along with AE showed interesting results. In particular:

1) the localization was a very precise indicator of the initial failure position (with an error of about 2mm on a measure base of 100-120mm, mainly due to sensor position uncertainty);
2) cumulative energy release for a given section and event counts are good candidates to differentiate between non-relevant events to critical failures, in particular a combination of (relatively) high counts and energy was an indicator of the MAT failure which lead to fibre pull-out and specimen total failure (as shown in [4]);
3) there are zones of the material which show an increase in events for a given time and then seem to become inactive, this – correlated to the static tests results –shows that a certain zone becomes permanently damaged but doesn't contribute to the failure until its size is critical;
4) on the connection between residual strength and AE signals a more extended study is being developed.

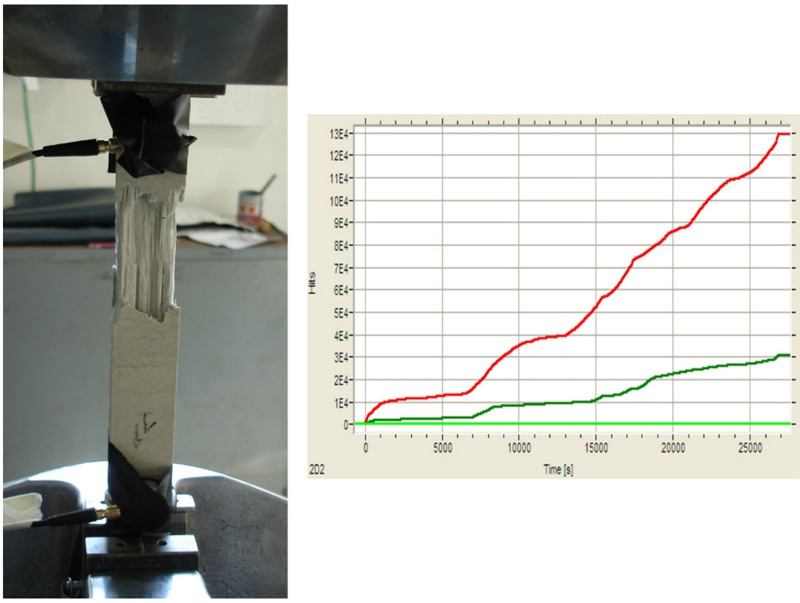


Figure 5: Broken specimen and AE signal associated to the fatigue test

## TOMOGRAPHICAL ANALYSIS

A 3D tomography of damaged specimens was made with synchrotron light at Elettra Trieste, at the SYRMEP beamline. This made it possible to investigate more precisely the damage modes of a pultruded specimen.

A typical non stressed specimen shows some inclusions which can be connected to the presence of an additive (which is added to the matrix to allow a better adhesion between the glass fibres and the polymer) and formed such "lumps". A stressed specimen is shown in Fig. 6; it's clear that the main failure mode is decohesion between packet of fibres, and fiber breakage in the longitudinal direction wasn't detected.

### *AE future developments in NDT*

Acoustic emission can play a relevant role in non-destructive techniques. Its characteristics allow it to be used as a mean of industrial inspection aid in certain applications, as pressure vessels or aerospace structures. AE allows a continuous event recording mean, avoiding timed inspections and allowing to set an "alarm" when a critical damage is detected. A

planar localization may allow to investigate the defect with a more local and precise method (rx, gas leak sniffers) avoiding to inspect the whole structure (which will take a lot of time).
Another future application of AE monitoring could be realtime monitoring of aerospace structures, both metallic and composite, where the monitoring of a crack propagation and size will (together with an on-board elaboration system) predict the residual life of the structure.

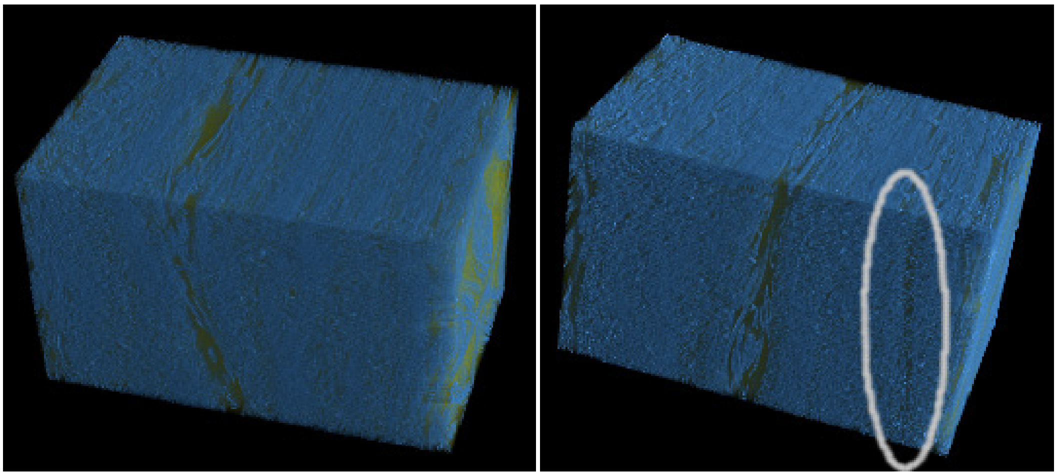

Figure 6: 3d tomography reconstructions show decohesion between fiber packets (right) compared to non-stressed specimen (left).

## REFERENCES


[1] Trevor F. Starr (ed) Pultrusion for Engineers, CRC Press, Woodhead Publishing Ltd., Cambridge, England, (2000).
[2] L. Vergani, Fracture and Damage of Composites, WIT, (2006) 49.
[3] Richard D. Finleyson. Handbook of Nondestructive Evaluation, chapter 10 - Acoustic Emission Testing, pp 10.1 – 10.39. McGraw-Hill Companies, (2003).
[4] G. Caprino, R. Teti, I. De Iorio, Predicting residual strength of pre-fatigued glass fibre-reinforced plastic laminates through acoustic emission monitoring, Composites: Part B 36 (2005) 365.