EUROPEAN SYNCHROTRON RADIATION FACILITY

INSTALLATION EUROPEENNE DE RAYONNEMENT SYNCHROTRON

Experiment Report Form

The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF.

Once completed, the report should be submitted electronically to the User Office via the User Portal:

https://wwws.esrf.fr/misapps/SMISWebClient/protected/welcome.do

Reports supporting requests for additional beam time

Reports can be submitted independently of new proposals – it is necessary simply to indicate the number of the report(s) supporting a new proposal on the proposal form.

The Review Committees reserve the right to reject new proposals from groups who have not reported on the use of beam time allocated previously.

Reports on experiments relating to long term projects

Proposers awarded beam time for a long term project are required to submit an interim report at the end of each year, irrespective of the number of shifts of beam time they have used.

Published papers

All users must give proper credit to ESRF staff members and proper mention to ESRF facilities which were essential for the results described in any ensuing publication. Further, they are obliged to send to the Joint ESRF/ ILL library the complete reference and the abstract of all papers appearing in print, and resulting from the use of the ESRF.

Should you wish to make more general comments on the experiment, please note them on the User Evaluation Form, and send both the Report and the Evaluation Form to the User Office.

Deadlines for submission of Experimental Reports

- 1st March for experiments carried out up until June of the previous year;
- 1st September for experiments carried out up until January of the same year.

Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report, in English.
- include the reference number of the proposal to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.

ESRF	**Experiment title:** *In situ mapping of fibre breaks in tensile failure of unidirectional carbon/epoxy composites using sub-second computed tomography and acoustic emission (AE) monitoring*	**Experiment number**: MA-3484
Beamline:	**Date of experiment**: from: 3rd May 2017 to: 5th May 2017	**Date of report**: 10/9/2017
Shifts:	**Local contact(s)**: Lukas Helfen (email: lukas.helfen@kit.edu) Elodie Boller (email: boller@esrf.fr)	*Received at ESRF:*

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Report:

Fibre failure is one of the main mechanisms involved in final failure of Carbon Fibre Reinforced Polymers (CFRPs), and a limiting factor of tensile strength. However, models are still unable to account for factors controlling the onset of unstable failure, and hence can not reliably predict behaviour at the highest load levels. This experiment performed at ID19 successfully captured progressive fibre-break formation in different CFRP material systems in conjunction with real time monitoring using acoustic emission.

A modified Deben CT5000 loading rig was used to apply and maintain incremental tensile loads to the specimens up to and including final failure with scans taken at each load step. High resolution (~0.7 micron) images were required to clearly visualise individual carbon fibres and be able to run an automated fibre break detection algorithm (developed in house specifically for this project). Speed of acquisition is another important factor as we did not want the specimens to endure high loads for prolonged periods such that stress relaxation effects and potential failure mid-scan could influence results. Due, in part, to the small field of view (~1.4mm^3) we used our tried and tested double edge notch specimen geometry to induce stress concentrations within the specimen to encourage final failure to occur within the scanned region of interest. Acoustic emission monitoring was performed by mounting sensors directly to the specimen (this had previously been proposed for use during expt MA636 but was not possible at that time), but away from the field of view of the synchrotron beam. Two sensors were used that enabled positional information from detected events (fibre breaks) to be located along the length of specimen between the sensors.

The main aims here were to: (a) Identify if it was possible to simultaneously acquire AE and SRCT information from a CFRP specimen loading in situ. (b) Use the information form the AE to better comprehend the chronological build-up of fibre breaks and clusters within these different materials systems and effectively increase the region of interest beyond that of the field of view of captured during the scan. (c) Assess whether AE could be used to improve the efficiency of these experiments – in particular from the point of view of informing when a specimen is nearing final failure and selecting appropriate points to

perform scans as opposed to the traditional pre-selection of %UTS values. (d) Reduce the time of acquisition such that we did not need to pause the loading test for scanning.
The experiment confirmed that it was possible to simultaneously acquire SRCT images of a CRFP specimen loaded in situ together with AE. The specimen used in these tests is very small and required physically small AE sensors in order that they could be mounted to the specimen and also fit within the loading rig. Since we were using two sensors (one above and one below the notched region) it was necessary to construct a cable management system to prevent the sensor wires from interfering with the beam during scanning.
Furthermore, when we initially set up the equipment, the AE sensors were detecting a lot of background noise – electrically isolating the loading rig from the rotation stage was found to reduce the level of noise to such an extent that useful measurements became possible.
Information was gathered as to the build-up of acoustic events during loading. Clear patterns were identified the showed an increasing rate of event detection as the specimen neared final failure. Since it was possible to monitor this information in real time, more informed judgements as to when a specimen is approaching final failure is possible. Furthermore, the ability to provide locational information along the length of the specimen helped to indicate whether the specimen was more likely to fail at the top of bottom of the notch. This information is incredibly valuable for future experiments as capturing the exact point of final failure is often illusive.
With regards to fast scans – the initial ambition was to perform dynamic loading with scan times approaching or even less than a second. However, although the scan time was reduced from previous experimental campaigns, we did not achieve scan times short enough to continuously load the specimen during scanning. None-the-less the experiment did provide significant advances and information for damage prediction models. In particular, information concerning the rate of indvidual fibre breaks was captured as a function of fibre stress (Figure 1) progressive fibre breaks were observed within the same co-planar cluster, as well as mutliple fibre breaks within the same fibre (Figure 2 & Figure 3). The experience and methods developed during this campaign will inform testing strategies and methods to improve future campaigns.

One article has been published on this work to date at the 3rd International Conference on Tomography of Materials and Structures ‘ICTMS2017’ Lund, Sweden, 26th – 30th June 2017

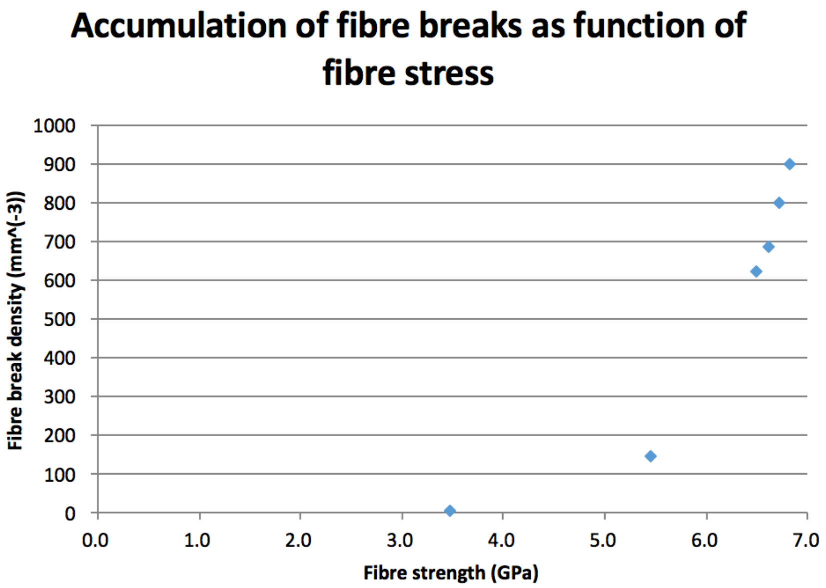

Figure 1 – Graph showing accumulation of fibre breaks as counted using automated detection algorithm as a function of fibre stress.

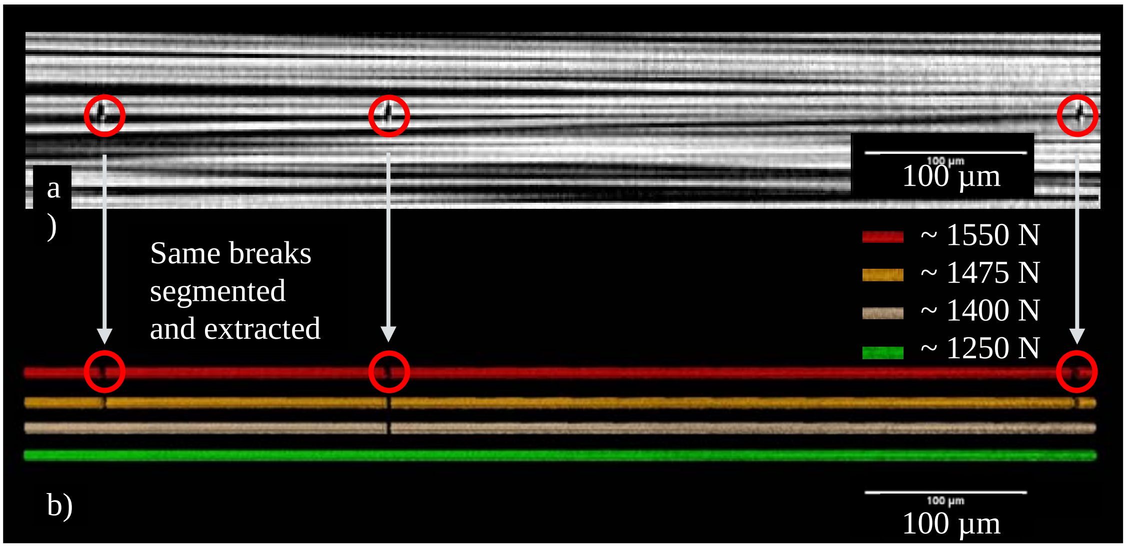

Figure 2 - Build-up of fibre breaks within an individual fibre as a function of increasing load. a) CT image showing 3 breaks within the field of view along a fibre; b) the same fibre as identified in (a) segmented and extracted from four different load steps.

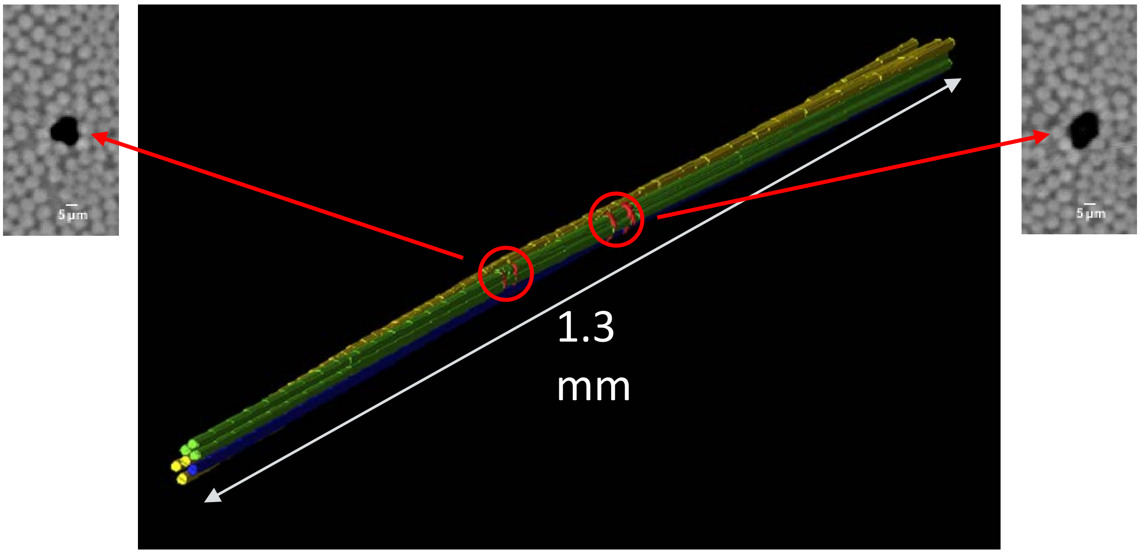

Figure 3 - Clusters observed along the same fibres observed at high load levels (higher than 90% nominal average UTS).