EXPLORING DIFFERENT APPROACHES FOR 3D X-RAY COMPUTED TOMOGRAPHY IMAGING OF COMPOSITES

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Summary: Synchrotron and laboratory X-ray computed tomography (CT) were used to investigate in situ and post-mortem damage in composites with the aim to compare image quality and damage detectability. Current challenges for composite materials in terms of image acquisition and analysis using both laboratory and synchrotron CT are discussed.

1. INTRODUCTION

X-ray CT has been widely recognised as a valuable non-destructive technique to obtain three-dimensional information on materials subjected to various load conditions [1]. For composites, both laboratory [2] and synchrotron CT [3] were demonstrated to provide detailed observations about damage initiation and propagation at the fibre scale (*i.e.* diameter of carbon fibre is 5-7 µm). Synchrotron CT allows performing experiments with high spatial and temporal resolution, particularly suitable to capture very short time phenomena. Laboratory CT, easier to access, is able to achieve similar spatial resolutions than synchrotron, but with a limited temporal resolution. On the other hand, laboratory CT resulted more appropriate for long tests (*i.e.* time-lapse studies under fatigue loading) or when dealing with big samples. This work reports some case studies where advantages, disadvantages and challenges for different imaging methods are discussed.

2. EXPERIMENTAL METHOD

Synchrotron X-ray CT experiments were conducted at the Swiss Light Source (SLS) on the TOMCAT-X02DA Beamline, Paul Scherrer Institut, Villigen, Switzerland. Monochromatic beam with an energy level of 19 keV was used with different settings, depending of the objective of the study:

- *In situ* scans (duration of 5 minutes for a tomogram) during loaded/unloaded state of the sample and by using different voxel sizes (0.69 µm and 1.6 µm)
- Uninterrupted rising *in situ* tensile loading using fast continuous scans with a voxel size of 1.1 µm and a temporal resolution of 1 s.

Laboratory X-ray CT experiments were performed on post-mortem samples at the Henry Moseley X-ray Imaging Facility at the University of Manchester by using conventional approaches (traditional cone beam) and helical scans. The material used in this comparative study is a particles-toughened carbon/epoxy (M21/T700) [4]. This material resulted particularly suitable for the aim of this work because: (i) the contrast between matrix and carbon fibre is relatively low, and (ii) matrix and toughening particles have a similar density. Double notched specimens were shaped from a laminate sheet with a thickness of 1 mm, obtained small coupons with a notch section of 1 mm. The layup used is a cross-ply.

3. RESULTS

The results obtained showed differences in terms of image quality between static synchrotron CT and fast experiments (due to the low exposure time and small number of projections). Although in fast scans the image

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quality was degraded, by using a voxel size on the order of 1 µm, small entities such as fibre breaks (see Fig. 1 in the highlighted region) can be distinguished. Fig. 1(a) was obtained using SLS in-house reconstruction code based on GRIDREC reconstruction method [5] and then applying a median filter to the reconstructed image, while Fig. 1(b) via the Paganin method [6]. Paganin enhances the contrast between matrix and toughening particles, Fig. 1(b), respect to Fig. 1(a), and it is particularly suitable in segmenting fully open cracks, as the case of the matrix cracks, which initiated at the notch. However, the contrast of small and narrow damage as fibre breaks is not particular improved, and the image is blurred in the fibre rich region, Fig. 1(b). The use of conventional reconstruction techniques seems more adequate to distinguish fibre failure, see Fig. 1(a). However, even if single fibre can be detected by eyes, this does not imply that image quality achieved is sufficient to perform automatic image processing of single failed fibres. On the other hand the use of fast scans provides invaluable qualitative information on the micromechanisms occurring immediately before of catastrophic failure.
Laboratory CT resulted particularly advantageous to extend the region of interest when helical scans were used, thus avoiding acquisition of multiple concatenated scans using conventional techniques. However, the acquired datasets are rather large and they require high-performance machines for image post-processing. Further work is needed to develop optimised methodologies for laboratory CT experiments on composites in order to decrease the acquisition time, enhance contrast and allow analyses on samples with different aspect ratios (*e.g.* composite panels).

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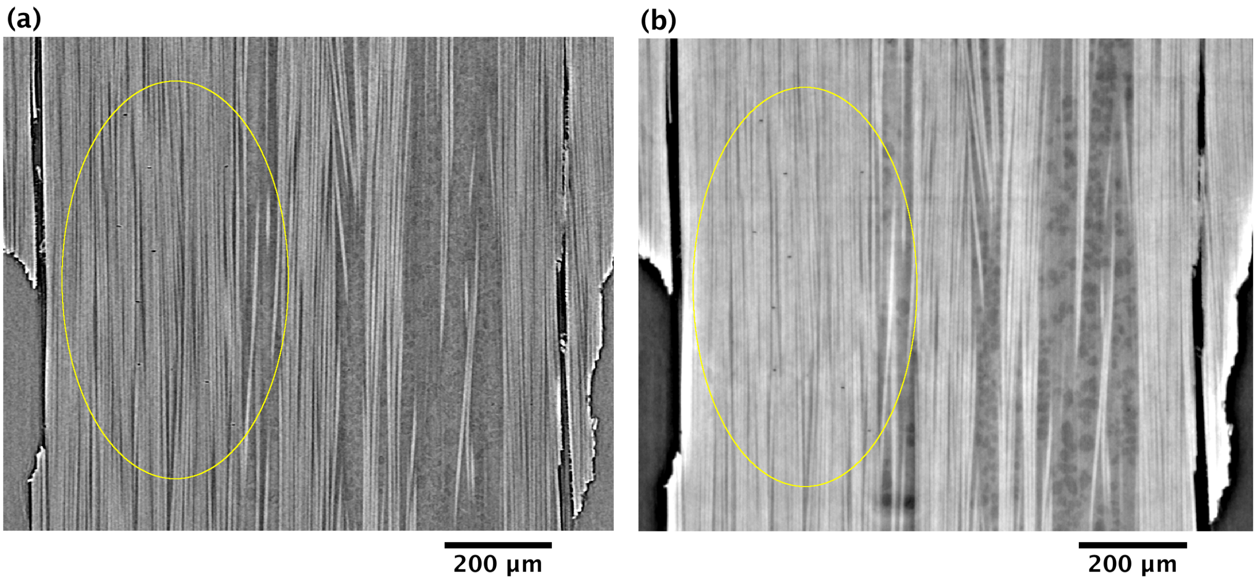

Figure 1 – CT slice parallel to the loading direction in the notch region by using: (a) GRIDREC reconstruction method [5] and median filter of the reconstructed image, (b) Paganin method [6]. Continuous fast scans were conducted at 19 keV using monochromatic beam, a voxel size of 1.1 μm and a temporal resolution of 1 s.