IN-SITU CYCLIC EXPERIMENT ON GLASS FIBER REINFORCED COMPOSITES MONITORED VIA μ-TOMOGRAPHY

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1. Introduction

The increasing demand for lightweight structures urges the development and utilization of innovative materials optimized for weight and mechanical performance. Among all material types, fiber reinforced polymer composites (FRPs) show one the greatest flexibility to adapt the material architecture to the applied loads. Although FRPs are employed in various industrial branches, there is an absence of the full understanding of their behavior in the whole service cycle.

Damage mechanisms occurring in FRPs are heterogeneous and initiate mostly in-depth and then propagate at different length scales. Hence, X-Ray computed tomography (XCT) is an appropriate inspection tool to monitor the material response in the bulk of the investigated specimen. The possibility for obtaining information on the full 3D material microstructure of the loaded specimen results in a new glimpse into the science of materials. This is especially favorable for FRPs since different damage mechanisms occur while prescribing load to the sample.

The aim of this in situ experimental study was to measure the 3D kinematics of a cyclically loaded dog-bone sample from the reconstructed scans obtained via μ-tomography. For that purpose, global Digital Volume Correlation (DVC) was used to evaluate displacement and strain fields within the glass fibre/polyester resin composite.

2. Experimental procedure

2.1 Material and Methods

The experimental investigation was performed on glass fibre reinforced polyester resin composites. The R-glass fibre mat yarns with an areal density of 300 g/m^2 and 50 mm long fibres were used as the reinforcement.

The dog-bone specimen was machined from a 5.6-mm thick GFRP plate. To ensure that the specimen would break in the ligament area and not in the grips, the central part was thinned with a radius of 39 mm. The ligament was 61-mm high, while the smallest cross-section of the sample was 5 × 5.6 mm^2.

The access to the true deformed GFRP composite microstructure acquired during in situ experiment via XCT were analysed with a volumetric correlation algorithm. The global (*i.e.* FE-based) DVC approach [1], in which the kinematic degrees of freedom are spatially coupled, was considered to determine the kinematics in the bulk of the dog bone specimen under uniaxial loading.T4 elements [2] with 32 voxel edges were used to faithfully mesh the curved geometry of the specimen.

2.2 Experimental setup

The X-ray μ-tomographic experiment was performed in the X50+ scanner (North Star Imaging) of LMT. A uniaxial specimen of the investigated GFRP was loaded in situ with a Deben testing machine (Fig. 1). The proposed loading device with nominal load of 20 kN is supported with four pillars that allow for the transfer of the applied load. However, the robustness of the loading platform and vertical supports exclude the possibility to use the tomograph turntable. Thus, two rotational actuators are mounted in the frame of the loading device. Consequently, they enable the loaded sample to be fully rotated (*i.e.* 360° or more) under load in addition to applying torsion.

2.3 Cyclic in-situ tomography experiment

From the results obtained in a previous study [3], it was decided to cycle the sample with maximum loads corresponding to 35%, 70% of the ultimate level (Fig. 2a). During the in situ test, six scans in loaded and unloaded stages were acquired. To perform the mechanical test in a reasonable time period, two acquisition parameters (*i.e.* HQ and LQ) were employed.

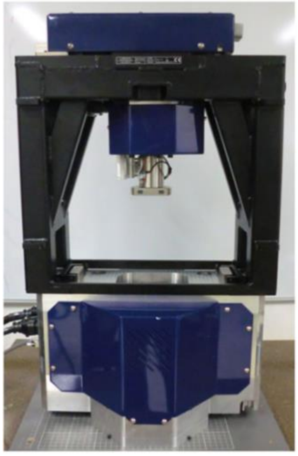

Fig. 1. Deben tension/torsion/compression testing machine

With the HQ settings (Fig. 2b), *i.e.* 800 projections, 50 ms delay, 20-frame average, 3 fps, the scanning procedure lasted approx. 2 h. Changing the number of averaging frames to 1 for the LQ settings (Fig. 2c) led to15 min acquisitions. Since two different 3D image qualities were selected, the first two scans of the mounted sample were acquired with no mechanical load.

Each tomographic scan was initially acquired with a definition of 1507 × 1507 × 1849 voxels, whose physical size was 14.6 µm, encoded as 8-bit deep gray levels. For those 3D images, the size of the ROI was adjusted to the sample geometry focusing on the thinned part of the dog-bone sample corresponding to a size of 610 × 410 × 1180 voxels.

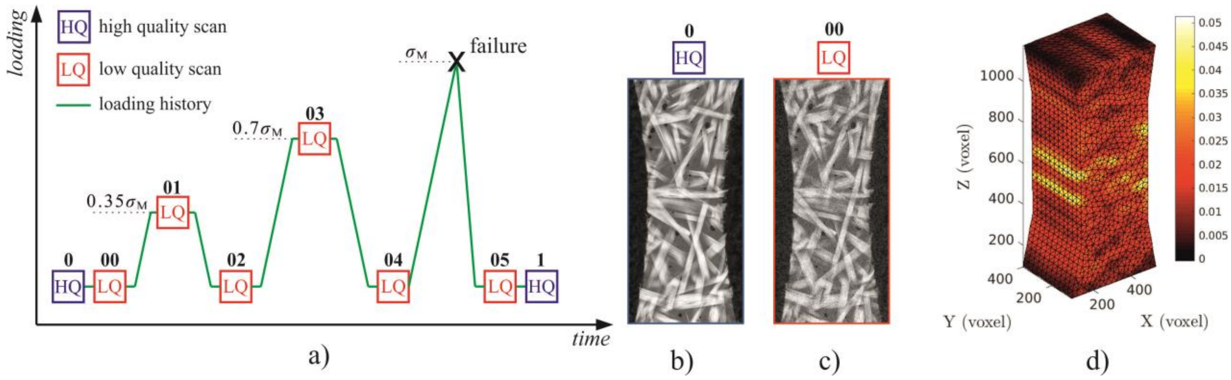

Fig. 2. (a) Schematic of the loading history and corresponding acquisitions. (b) Slice of the HQ scan 0. (c) Slice of the LQ scan 00. (d) Measured maximum principal strain via DVC.

3. Results and Conclusions

The correlation was performed between the undeformed volume (scan 0) and 'deformed' ones (scans 00-1). The HQ scan was taken as the reference due to the lowest noise level. Moreover, the most detailed information regarding the GFRP microstructure is registered with respect to the latter. Even though scans with different noise level were considered, global DVC successfully measured the kinematics over the entire 3D volume.

The maximum principal strain field evaluated for scan 3 is shown in Fig. 2d. From the measured map, several highly strained regions can be observed. The highest levels of strain are established in two horizontal bands on the left side of the notch. Furthermore, on the face normal to Y direction, several strain localizations are identified and quantified.

References

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