In situ study of strains in a 3D Printed Composite (basalt-polylactic acid) by Dual X-Ray Imaging and Diffraction

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Abstract. This work aims to measure the partitioning of strain in the architecture of 3D printed unidirectional composites of basalt fibre and PLA (polylactic acid). The in situ experiments combined synchrotron dual X-ray diffraction and imaging to achieve simultaneous measurement of the elastic and total strains at the same location during tensile loading of notched specimens.

Possible Sessions

Testing of Additive Material, Tomography & Radiography

Introduction

In 3D printed composites, additive manufacturing enables precise control of structural anisotropy, offering new opportunities for tailoring mechanical properties [1]. How the complex architecture affects local deformation and damage accumulation remains to be fully understood. To investigate the relationship between microstructure, deformation and damage, a PLA/basalt 3D printed composite was fabricated with unidirectional short fibres. A novel strain measurement technique - dual imaging and diffraction (DIAD) - was applied to study its tensile behaviour. Synchrotron X-ray diffraction and radiography provided quantitative measurements of strain evolution. High resolution synchrotron X-ray tomography was also applied to image the 3D spatial distribution of fibres, pores and mechanical damage.

Method

The in situ experiment with V-notched tensile specimens (4 layers of unidirectional filaments, total thickness ~ 1 mm) was conducted at the K11 (DIAD) beamline at the UK Diamond Light Source [3]. The load was applied parallel to the filament direction. The X-ray beam was parallel to the layers plane. Monochromatic X-rays of 13.8 keV were used for diffraction in transmission, mapping the notched region (~ 200 x 1000 um) with a 50 × 50 um beam, and 15 KeV X-rays were used simultaneously for radiography (field of view ~1 x 1 mm, 0.5 um pixel). Observations were taken as the sample was strained to failure in ~40 steps with displacement intervals of 50 um. After peak load, a computed tomograph (3000 radiographs, 0.5 um voxel) was obtained to visualise the post-failure microstructure. The 2D diffraction images were post-processed in DAWN (Data Analysis WorkbeNch). Azimuthal integration was performed to convert the 2D diffraction patterns (partial Debye-Sherrer rings) into 1D intensity vs. q-value profiles in the loading direction (integration over caking angle of 30° was used increase the signal to noise ratio). These were analysed to quantify the positions of peaks of intensity that were due to scattering by the short-range order in the amorphous fibres and matrix. The radiographs were analysed by digital image correlation (DIC) using the LaVision DaVis StrainMaster 8.2 software to extract their relative displacement fields. The objective was to obtain the relation between the total strain and elastic strain in the fibres and matrix during the tensile loading and failure of the PLA/basalt composite.

Results and Discussion

The typical diffraction spectrum in Fig. 1(a) has two characteristic broad peaks. The peak at q ≈ 1.2 Å^{-1} is from the PLA matrix, and the weaker peak at q ≈ 2.1 Å^{-1} corresponds to the basalt fibres [4]. The peaks are broad due to the lack of long-range order in these materials. Fig. 1(b) shows the effect of load on the basalt after denoising using Gaussian filtering (σ = 10). The gradual shift to lower q-values then a reverse trend at high loads indicates elastic stretching of the fibres and then relaxation due to matrix yielding or fibre sliding, as shown in Fig. 1(c). The elastic strains may be calculated from the change in peak position. The radiographs were analysed by DIC to determine the displacement field at each load stage. An example result for the displacements in the Y loading direction is shown in Fig. 2(a). The strain at the notch was evaluated from the displacement gradient in each filament layer, as shown for a single layer in Fig. 2(b). It increased with applied load until failure. Fig. 2(c) shows that average strains of up to 0.13 were observed.

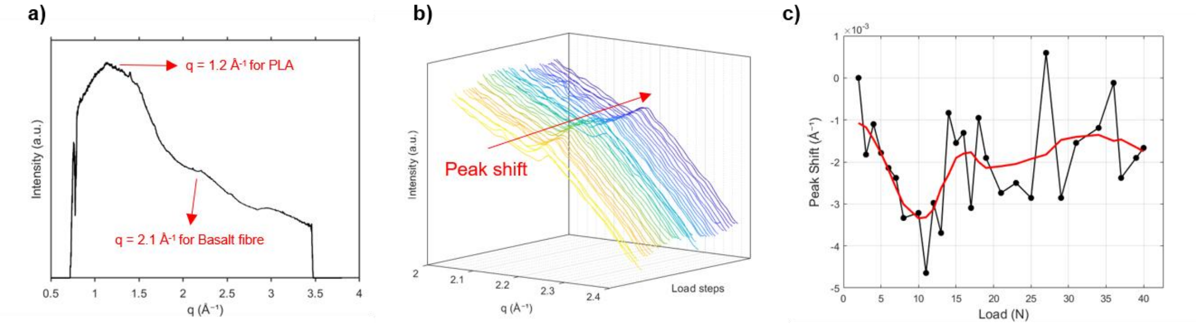

Fig. 1. Synchrotron X-ray diffraction: a) typical XRD spectra; b) effect of load on the basalt peak (after Gaussian filtering); c) basalt peak shift relative to the unloaded stage.

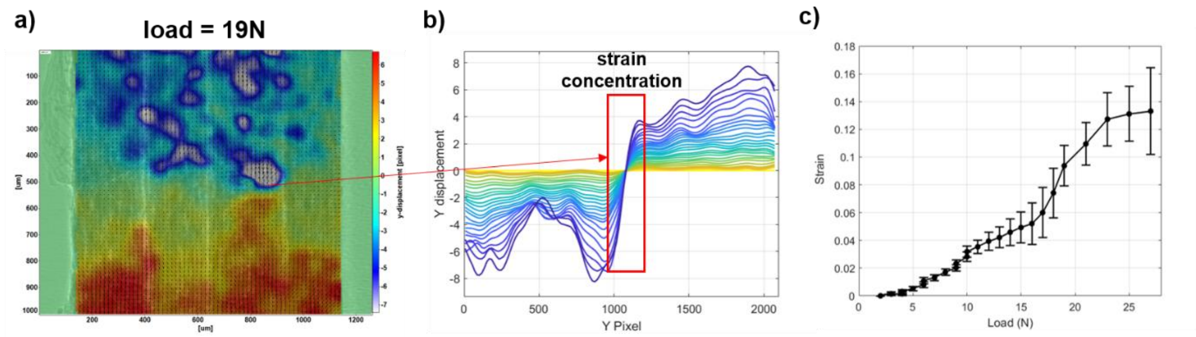

Fig. 2. a) Example of the vertical (Y)-displacement field at 19 N load obtained by DIC of radiographs; b) variation of average Y-displacement in the third layer with increasing load (the position of the notch strain concentration is marked); c) the notch strain, obtained from the local gradient of the displacement field in the third layer.

Conclusion

The mechanical behaviour of a unidirectional 3D printed PLA/basalt composite has been studied using in situ dual imaging and diffraction with synchrotron X-rays. The applied total strain at the notch increased with load and was measured using DIC of radiographs. The elastic strain in the fibres and matrix may be obtained from synchrotron XRD, which can detect the broad peaks from their short-range order. The correlation of these strains is being used for a quantitative analysis of the evolution of stress partitioning as the composite fails in tension.

References

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