Volume decomposition of tomography data to detect damage in mini-composites

C.A. Middleton[1a], K. Amjad[1,2], W.J.R. Christian[1], A.M. Hilmas[3], C. Przybyla[3], E.A. Patterson[1]

[1]Department of Mechanical and Aerospace Engineering, University of Liverpool, Liverpool, UK, [2]UK Atomic Energy Authority, Culham Centre for Fusion Energy, Abingdon, UK, [3]Materials and Manufacturing Directorate, Air Force Research Laboratory, USA

[a]ceri.middleton@liverpool.ac.uk

Abstract. Tomography data collected during tensile loading of a ceramic matrix mini-composite specimen has been processed using volume decomposition. The original volumetric datasets were represented by one-dimensional feature vectors, which were orders of magnitude smaller than the original data. Comparisons between datasets at increasing tensile load were then carried out in feature vector space, allowing damage location, growth and morphology to be determined. This decomposition technique has the potential to be applied to data collected using a variety of volumetric techniques, on a range of materials.

Possible Sessions

8. Fatigue & Fracture 24. Testing of Composite Materials 27. Tomography & Radiography

Introduction

Fibre reinforced ceramic matrix composites (CMCs) have an increased toughness and an ability to withstand high temperatures, so have the potential to be used in a range of engineering applications [1,2]. In order to understand the mechanical behaviour of these materials, their complex microstructures require characterisation [3,4]. One technique to characterise these microstructures in three dimensions is the use of X-ray computed tomography. In previous work, indications of damage in tomographic datasets have been located using manual analysis of the grey-level intensity values or phase segmentation through deep-learning [3,5].

As an alternative approach, here, we apply orthogonal decomposition [6,7] to damage detection in the tomography datasets. This technique has previously been applied to two-dimensional datasets from a range of techniques to detect and track damage [8,9]. Recently, this technique has been extended into three dimensions to make comparisons between volumetric data for model validation [10].

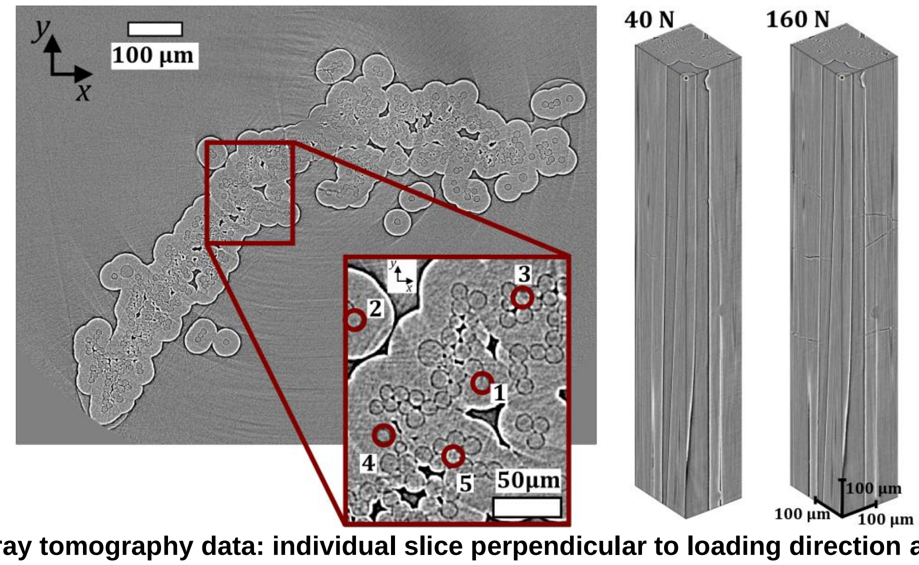

Figure 1. X-ray tomography data: individual slice perpendicular to loading direction at lowest load level, with inset indicating extracted bulk region and fibres (left); extracted bulk stacks at lowest and highest load levels, where matrix crack growth is visible in second stack (right)

Methods

A mini-composite specimen (Hi-Nicalon™ Type S (HNS) fibres, coated with boron nitride (BN) with an overlayer of a silicon carbide (SiC) matrix) was loaded at four tensile levels at the Advanced Light Source at the Berkeley National Laboratory in Beamline 8.3.2. X-ray computed tomography datasets were collected in situ at the four loads (40, 80, 120, 160 N).

Individual fibres and a bulk volume were extracted from the full datasets (Figure 1), then separated into approximately cubic sub-volumes for processing. Orthogonal decomposition was carried out using the method of Amjad et al. [10] for each sub-volume, then the feature vector difference between sub-volumes at equivalent positions in datasets at different loads was calculated.

Results

Results from the two approaches to data extraction can be seen in Figure 2, where high calculated feature vector differences correspond to damage observed in tomography datasets.

Individual fibres. The results from processing of one fibre show peaks in feature vector difference, which align with damage visible in sections of the extracted fibre tomography data. Growth of these peaks corresponds to the timing of damage events at higher tensile loads.

Bulk volume. The results from the extracted bulk volume show that damage position and growth is indicated by high feature vector difference, which aligns with the cracks visible in tomography data of the bulk volumes in Figure 1.

Combining the individual fibre and bulk results show that the indications of damage generated by the two approaches align. The morphology of the damage through the volume can also be determined.

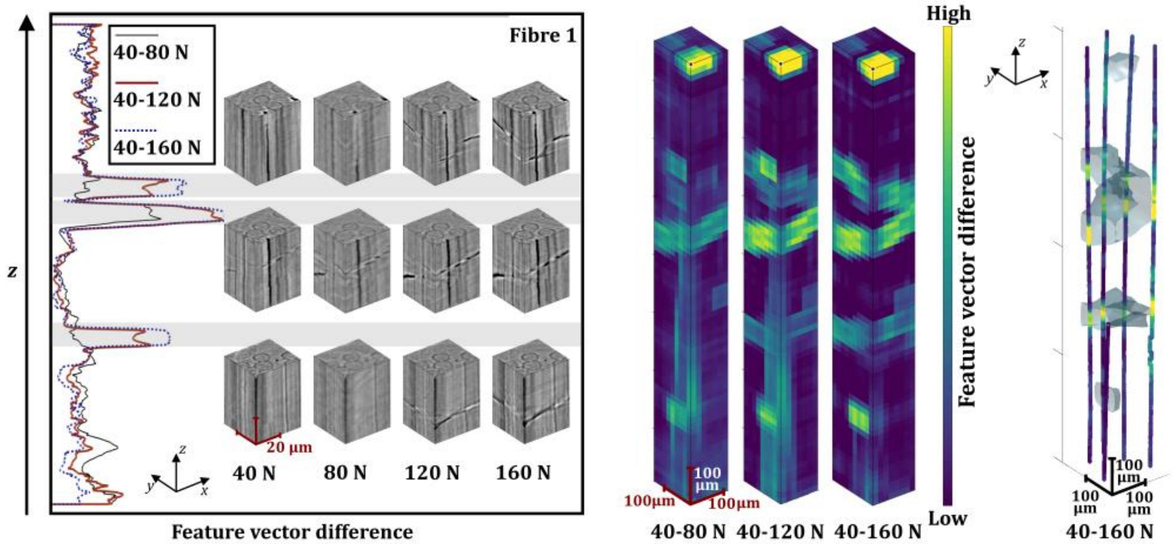

Figure 2. Results from volume decomposition of one individual fibre (left); bulk volume (centre) and combination of bulk and five individual fibres (right).

Conclusions

Volumetric decomposition has been applied to tomographic data of mini-composite specimens. Comparisons of data collected at progressive tensile loads have been carried out in feature vector space, resulting in quantitative information on the location, morphology, and growth of damage.

This work demonstrates that the orthogonal decomposition technique has the potential to be applied to damage detection in volumetric data from a range of techniques and materials.

Acknowledgements

This work was sponsored by the Air Force Office of Scientific Research, Air Force Material Command, USAF under grant number FA8655-20-1-7034. The U.S. Government is authorised to reproduce and distribute reprints of Governmental purpose notwithstanding any copyright notation thereon. Maj. David Swanson (EOARD) was the program officer for this grant.

References

[1] D. Brewer Mat Sci Eng A Vol. 261 (1999) p. 284–91. https://doi.org/10.1016/S0921-5093(98)01079-X.

[2] R. Naslain Compos Sci Technol. Vol 64 (2004) p. 155–70. https://doi.org/10.1016/S0266-3538(03)00230-6.

[3] A. Badran, D. Marshall, Z. Legault, R. Makovetsky, B. Provencher, N. Piché, et al. J Mater Sci 2020;55:16273–89. https://doi.org/10.1007/s10853-020-05148-7.

[4] B. Swaminathan, N.R. McCarthy, A.S. Almansour, K. Sevener, T.M. Pollock, J.D. Kiser, et al. J Eur Ceram Soc Vol 41 (2021) p. 3082–93. https://doi.org/10.1016/j.jeurceramsoc.2020.05.077.

[5] A.M. Hilmas, K.M. Sevener and J.W. Halloran. J Am Ceram Soc (2020) p.3436–47. https://doi.org/10.1111/jace.17017.

[6] C.M. Sebastian, E. Hack and E.A. Patterson. J Strain Anal Eng Des Vol. 48 (2013) p. 36–47. https://doi.org/10.1177/0309324712453409.

[7] Comite Europeen de Normalisation (CEN). CWA 16799:2014. (2014)

[8] C.A. Middleton, M. Weihrauch, W.J.R. Christian, R.J. Greene and E.A. Patterson. R Soc Open Sci Vol. 7 (2020) p. 200823. 200823.https://doi.org/10.1098/rsos.200823.

[9] W.J.R. Christian, K. Dvurecenska, K. Amjad, J. Pierce, C. Przybyla and E.A. Patterson. R Soc Open Sci Vol. 7 (2020) p. 191407 https://doi.org/10.1098/rsos.191407.

[10] K. Amjad, W.J.R. Christian, K. Dvurecenska, D.H. Mollenhauer, C.P. Przybyla and E.A. Patterson. IEEE Access Vol. 11 (2023) p. 123401–17. https://doi.org/10.1109/access.2023.3328326.