Early-Stage Fatigue Damage Development of 3D Woven Glass/Carbon Composites Using Synchrotron X-Ray Computed Tomography

L. Wu[1*], P. Potluri[1], and P.J. Withers[2]

[1] Northwest Composites Centre, Department of Materials, School of Natural Sciences, The University of Manchester, M13 9PL, UK
[2] Henry Royce Institute, Department of Materials, School of Natural Sciences, The University of Manchester, M13 9PL, UK
[*] Presenting author (leping.wu@manchester.ac.uk)

Abstract: The X-ray Computed Tomography is an excellent technique for investigating the material microstructure and its mechanical deformation behaviour by time-lapse scanning. Here, we first present the development of short beam shear fatigue damage at the early stage of fatigue life for 3D woven glass/carbon composites. The fatigue damage was monitored by the synchrotron X-ray Computed Tomography with a constant loading to open the cracks at different numbers of cycles. Many damage features and their damage relationships with dry fabric structure and the damage sequences have been identified and monitored globally. At the beginning of the fatigue test, the local tensile stress concentration led to a local intra-tow plastic crack at the bottom fibre tows. More damage was observed after 3000 cycles, which happened across the specimen. A 2D DIC imaging was also collected to monitor the surface stress/strain distribution to correlate with the DCT image. Future simulation and modelling work will also be beneficial from this research.

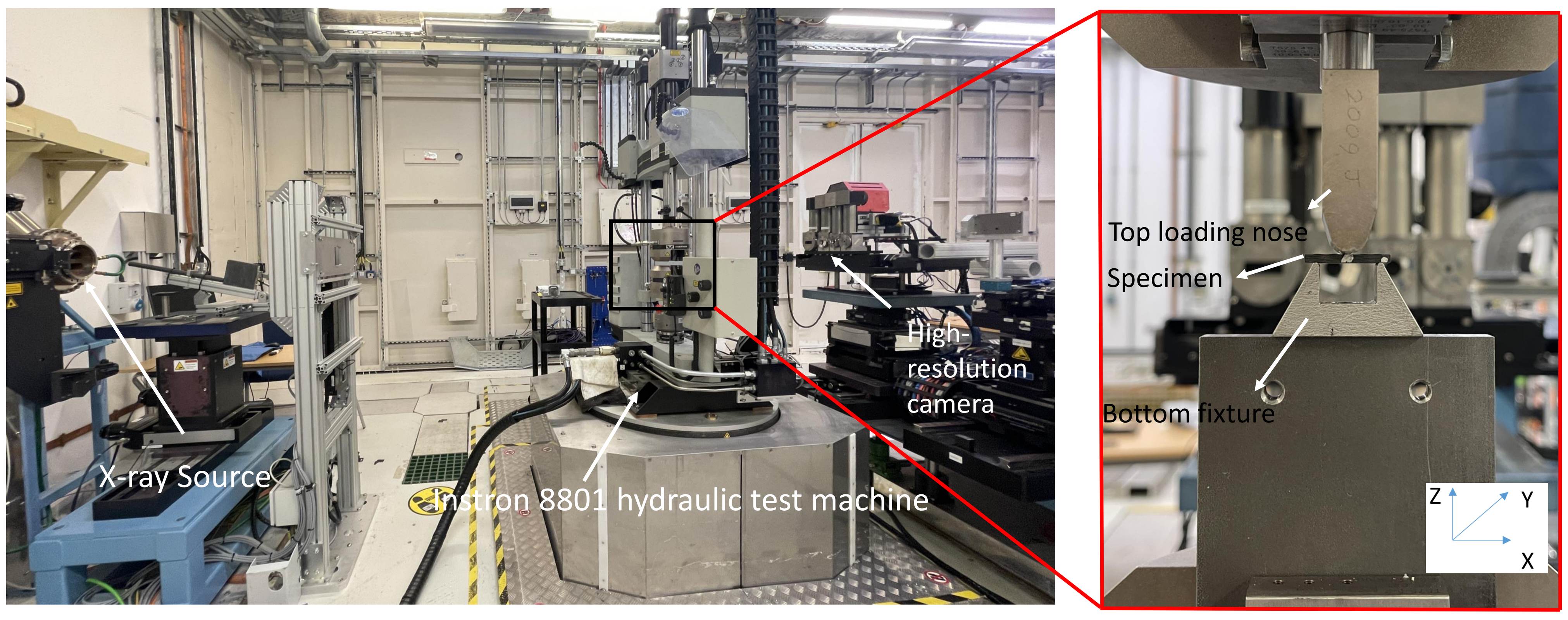
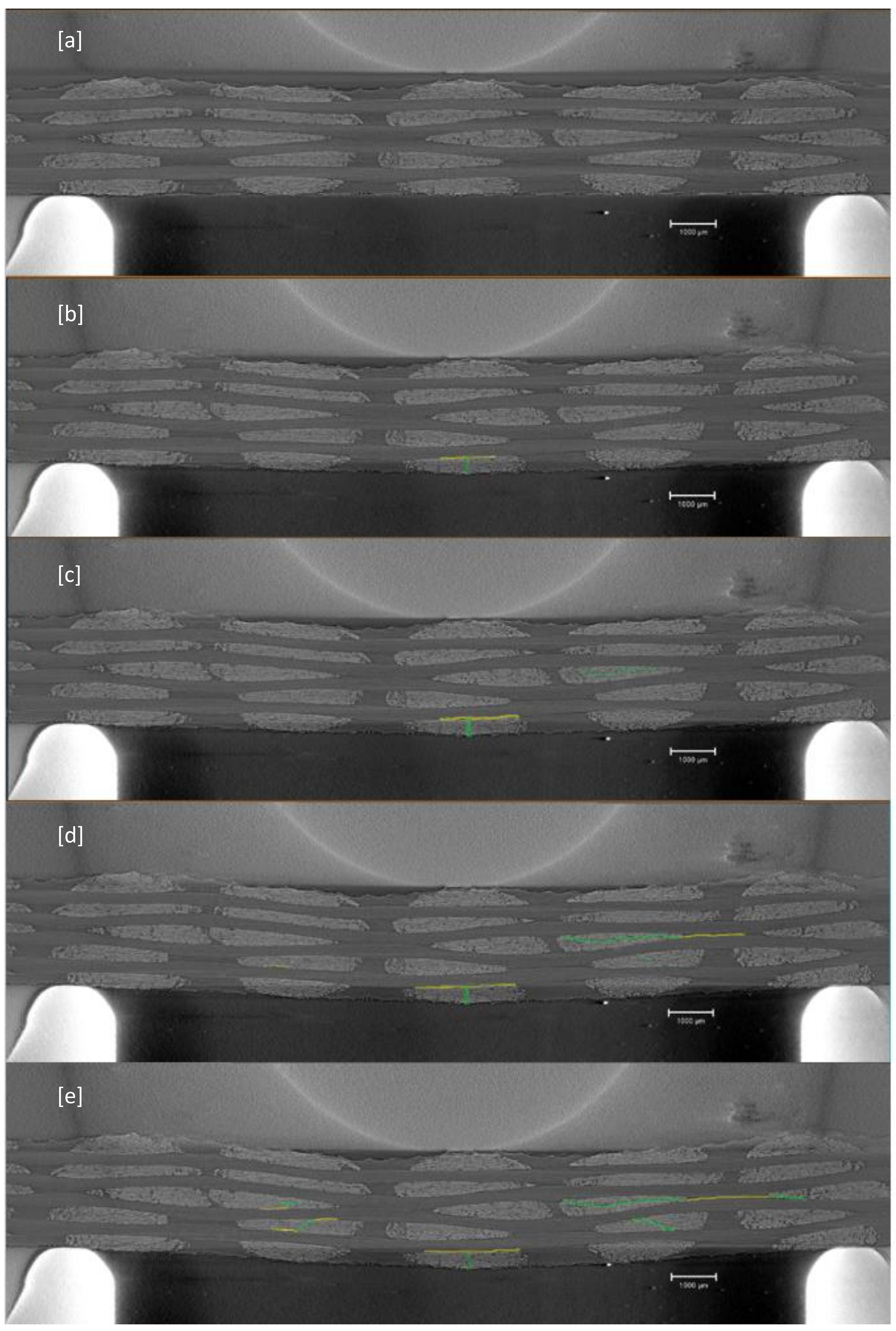


Figure1, Photography of the experimental set-up on the I-12 beamline at Diamond Light Source, showing the short beam shear fatigue loading of the composite by Instron 8801 in the sample stage, the details of samples set-up can be seen in the magnified insert.

Experimental methods: the 3D woven orthogonal preform was manufactured at the University of Manchester, then infused with epoxy resin by VARTM. The interlaminar shear strength was determined before the fatigue testing using the three-point bending fixture shown above. The maximum fatigue stress level in this research is 70% (which is corresponding to 1kN) with an R ratio of 0.1 and 4 Hz loading frequency. The fatigue was interrupted at every one thousand cycles and the synchrotron X-ray CT scanning data was acquired at 53 kV, exposure time of 0.02s and 2691 projections among the 140 rotation angles due to the two columns of Instron rig.



- From Figure 3 [a] to [e]/, The cracks appear in the centre of the lower side of the specimen. With the increasing of cyclic loading, the debonding cracks propagates to a weft/warp delamination.
- In figure 3 [c]-[e], a transverse debonding crack was observed between the loading roller and supporting roller at one side of the specimen and it grows longer along X-direction towards to the right side, and forms a transverse delamination in the adjacent weft/warp interface.
- In figure 3 [e], the similar transverse debonding associated with delamination also happened on the left side of the specimen and distributed evenly through the width of the specimen, but there is still no wide connectivity between each crack.

Figure 3, progressive fatigue damage development morphologies of the SBS specimen at different stages of fatigue loading: [a] reference imaging, [b] 1000 cycles, [c] 2000 cycles, [d] 3000 cycles, [e] 5000 cycles. Green: Debonding; Yellow: Delamination

Results and discussion

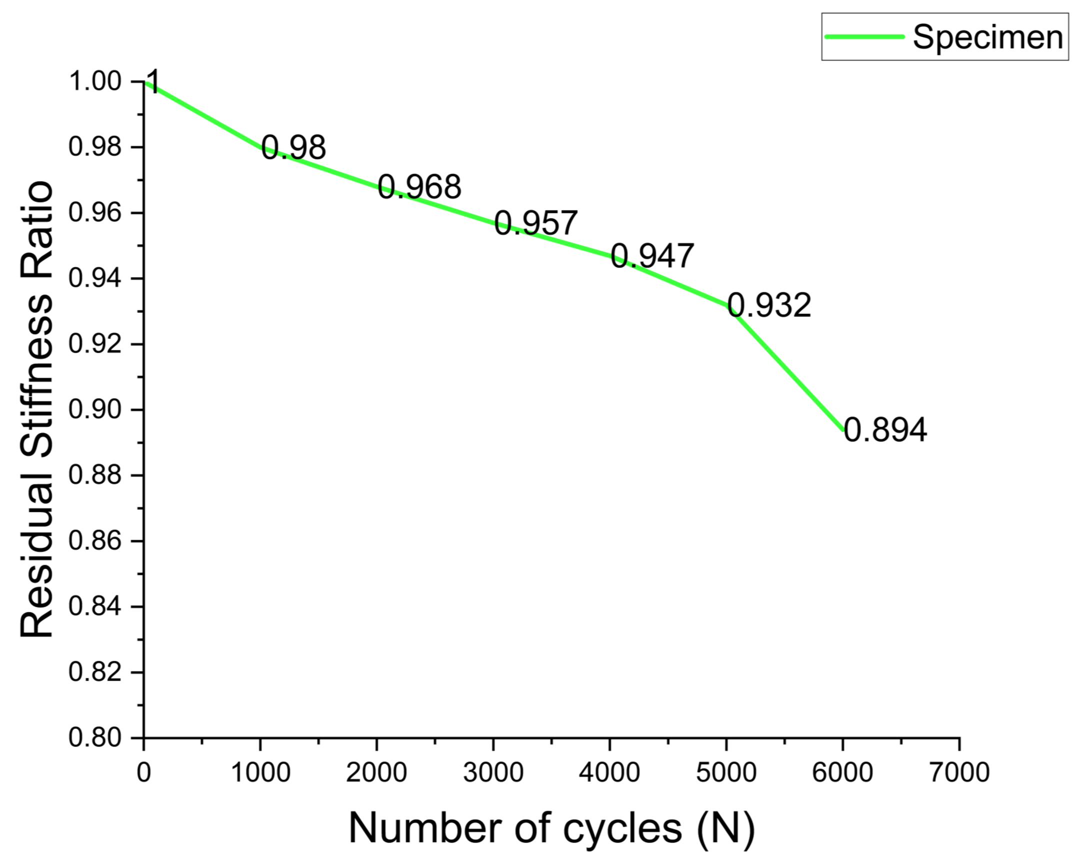


Figure 2, the Stiffness reduction was monitored and recorded using Instron 8801 hydraulic test machine

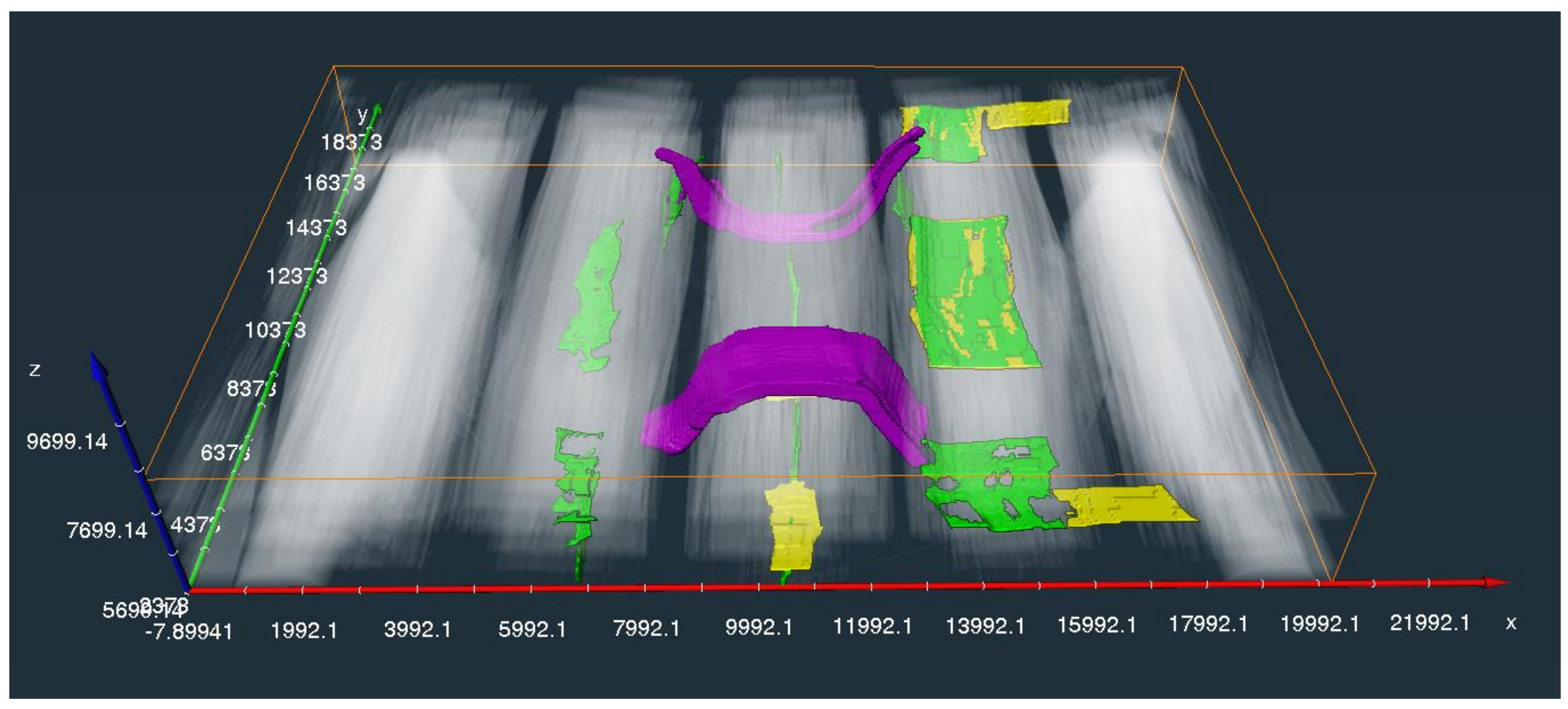


Figure 4, the 3D volume rendering showing the global cracks distribution of the sample after 5000 cycles loading. (For easier reading, only weft bundles (white) and part of the Z-binder (Purple) are rendered.) Green: Debonding; Yellow: Delamination.

- The bottom debonding crack are thorough the whole sample along Y-direction. The Z-binder arrests the crack effectively. Especially the Z-binder away from X-direction goes through the bottom and the stress redistribution leads to a weft/matrix debonding.
- The Z-binder also plays a positive effect in prevent the connection of transverse cracks. The isolated cracks will prevent the formation of main fatigue to increase fatigue life.
- By correlating with the DIC strain map (Figure 5), the sample is more sensitive to the positive shear stress rather than the negative shear stress, and severer damage was observed around positive region.

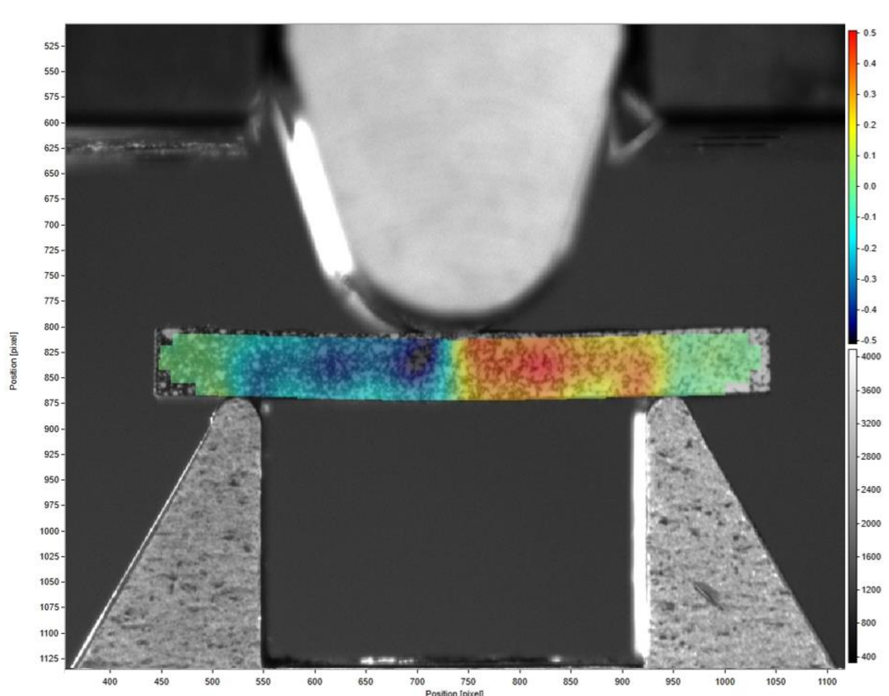


Figure 5, Full Field strain distributions measured by DIC

Conclusions:

- This study shows the short beam shear fatigue damage develop sequence and its distribution by In-situ Time-lapse X-ray CT and correlated with the DIC
- The delamination and debonding damage propagation tends to be arrested and disconnected by the existence of Z-binder. This allows damage to be more evenly distributed and extend the fatigue life.

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MANCHESTER 1824 The University of Manchester
NXCT National X-Ray Computed Tomography
RTC Robotics & Textile Composites Group
diamond
HENRY ROYCE INSTITUTE