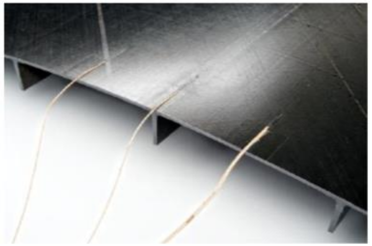

A data driven based methodology for structural health monitoring with distributed optical fibre sensors

ICCM23 Conference@13:50, 2th August 2023

Zhengquan Shen, Yiding Liu, Wenhao Li, Anubhav Singh, Tianyu Chen, Shijun Guo and Darren J. Hughes

University of Hertfordshire

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Structural damage monitoring: current scenario

Offline inspection: Non-destructive inspection

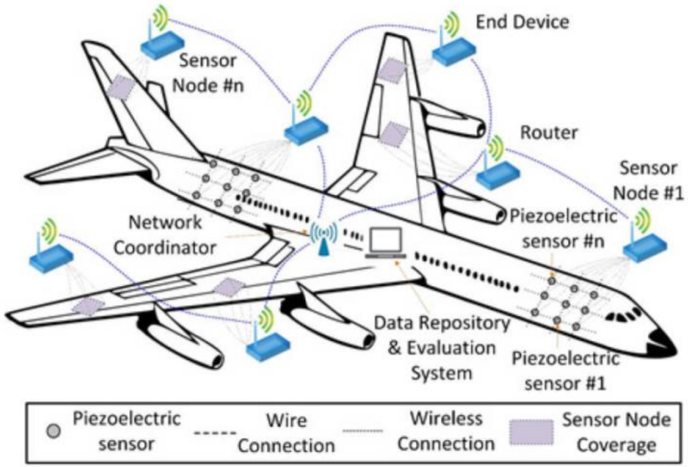
- Ultrasonic scanning
- X-ray tomography

- Periodic inspection of “hot spots”
- Reliance on operator experience
- Time lost in dismantling and reassembly

Online inspection: Condition-based inspection

- Piezoelectric wafer sensors
- CVM (Comparative Vacuum Monitoring) sensors
- Fibre Bragg grating sensors

- Provide local damage data in close proximity of sensors
- Add significant weight to aircraft



“A large number of sensors were required to detect damage, thus the cost due to the weight increase from the sensors was an order of magnitude higher than the cost saved by using SHM”- Dong et al.

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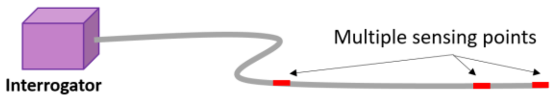
Dong T, Kim NH. Cost-Effectiveness of Structural Health Monitoring in Fuselage Maintenance of the Civil Aviation Industry. Aerospace 2018;5:87.

Opportunities

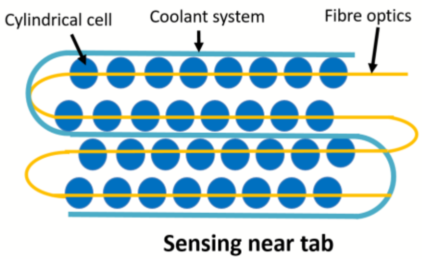
Development of continuous optical fibre sensing

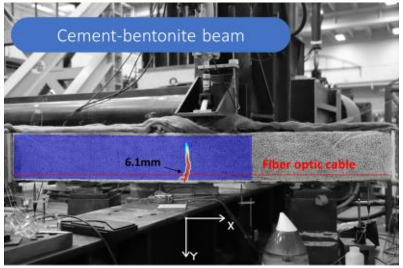
- Fabry-Perot sensors
- Mach-Zender sensors



- Fibre Bragg grating (FBG)

- Rayleigh scattering
- Brillouin scattering
- Raman scattering

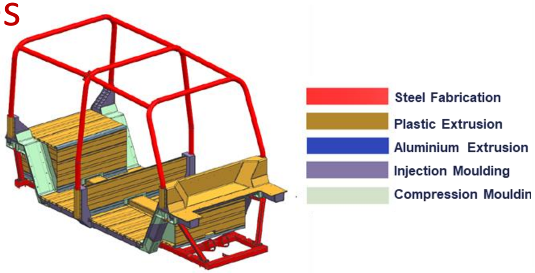




- ➢ Continuous thermal and mechanical monitoring in real time.
- ➢ Robustness, high accuracy and light weight

Thermoplastic braided composites

- ➢ Recyclability/Reuse
- ➢ Rapid processability
- ➢ Brainstorm, Amicable, Loris Projects



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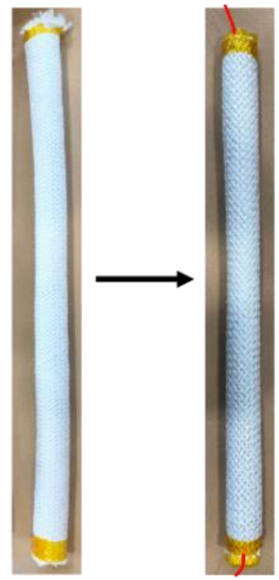
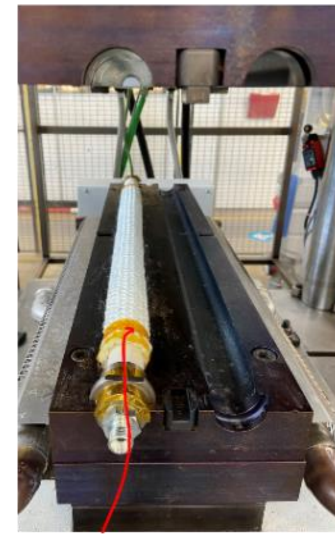
Manufacturing process development

Braiding of multi-layer preform

Preform preparation
Embedding optical fibre

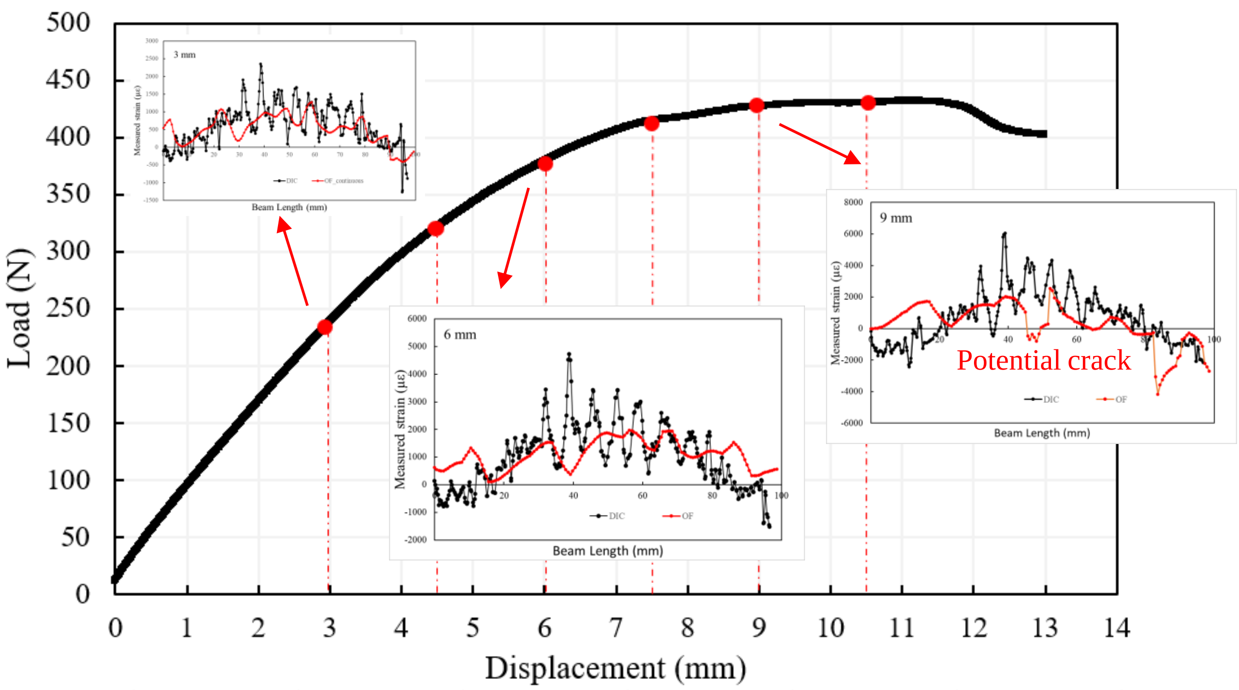


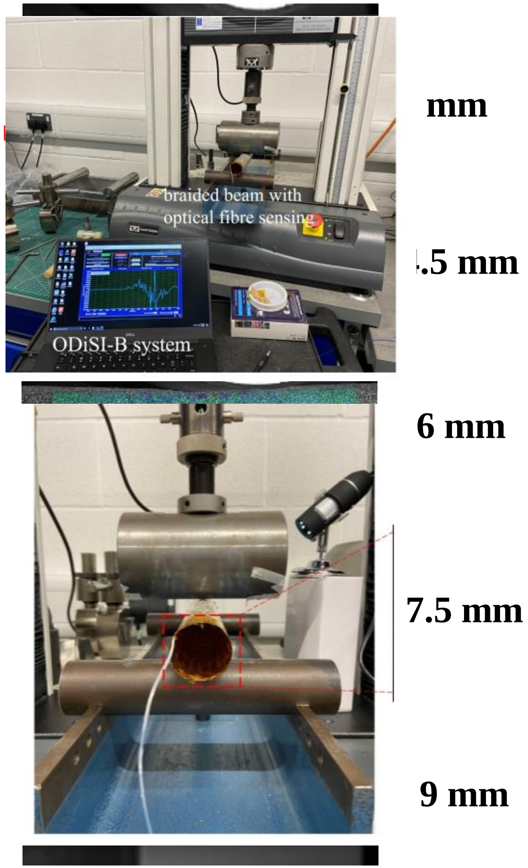
Moulding in RVM press



RVM: rapid variothermal moulding

Demonstrator SHM during three-point bending - Continuous test with DIC





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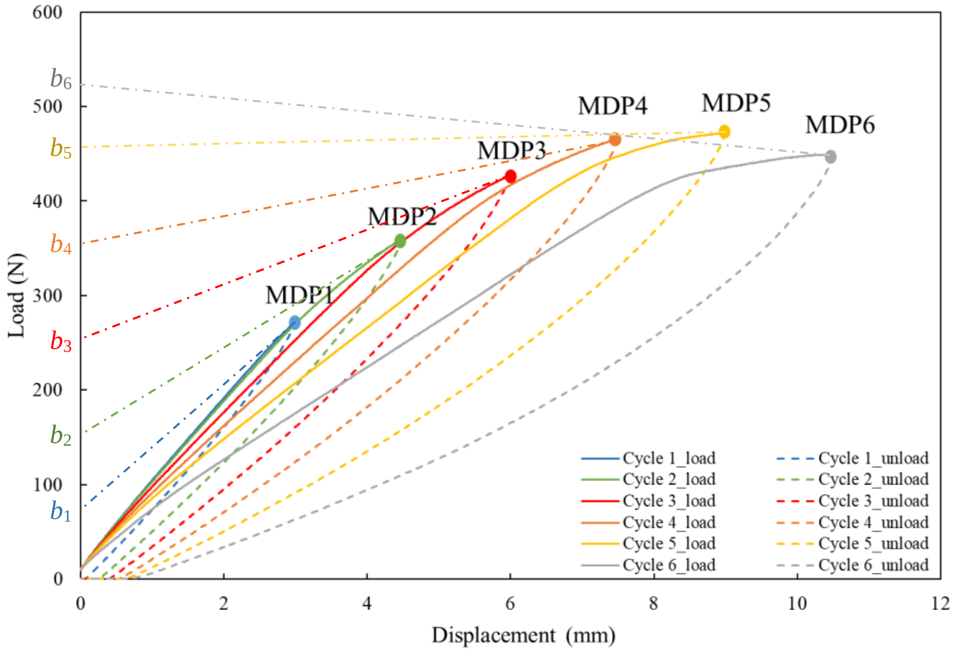
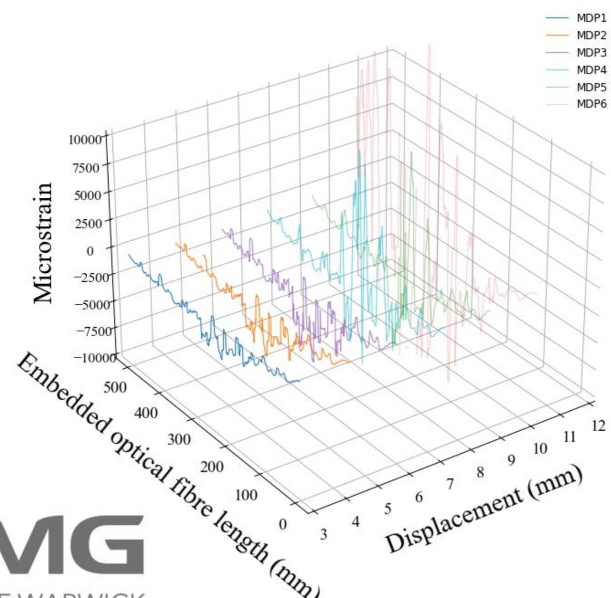
Demonstrator SHM during three-point bending - Interrupted test to observe crack



Load cycle	Max dis (mm)	Max load (N)
1	3	272.96
2	4.5	360.90
3	6	427.46
4	7.5	465.77
5	9	471.38
6	10.5	447.94



- To determine repeatability associated with strain measurement
- Relocate the key to adjust for beam deformation

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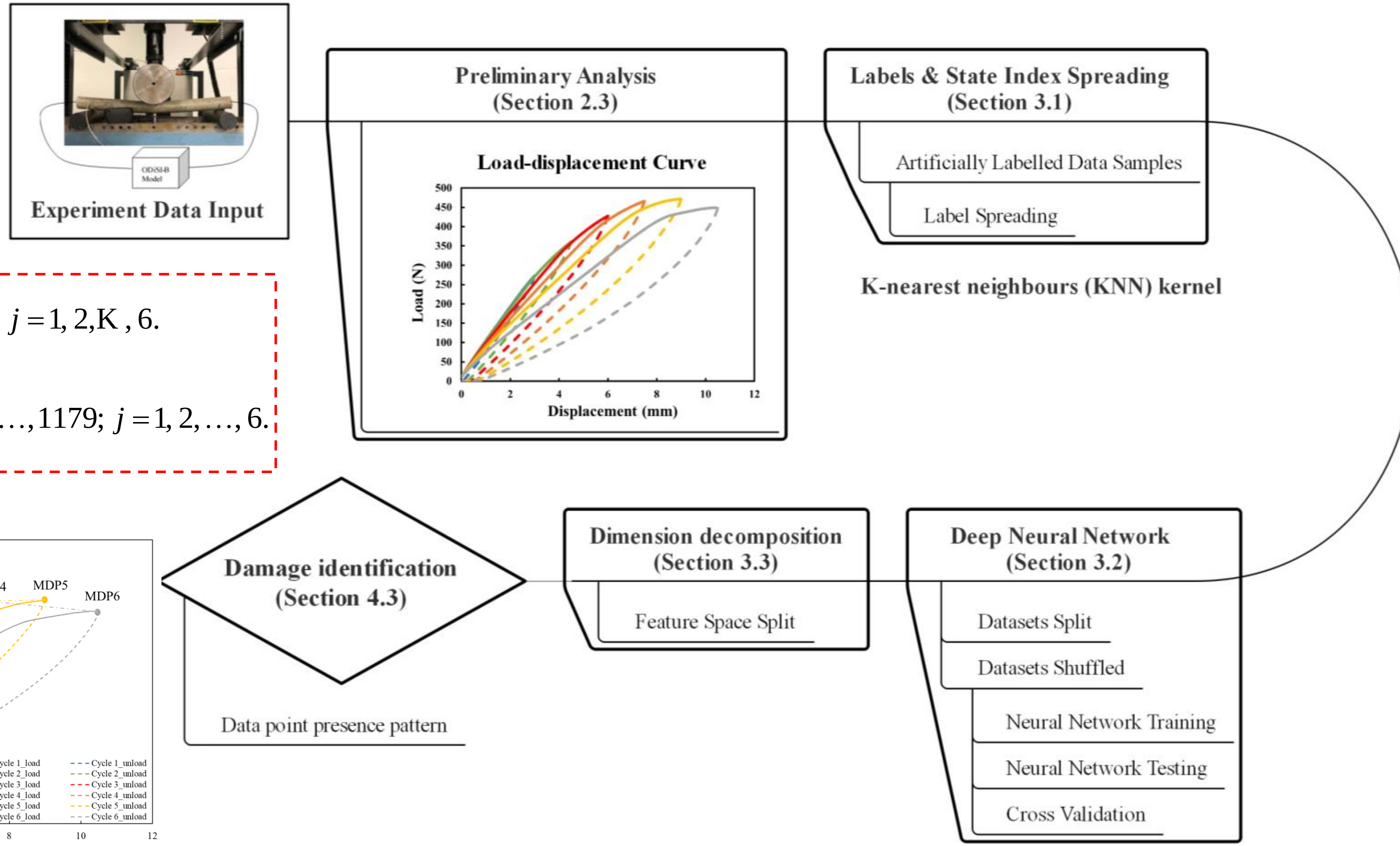
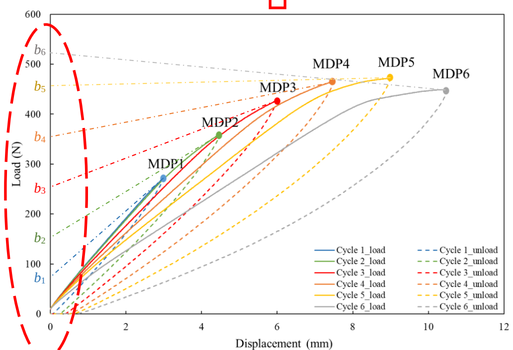
Approach

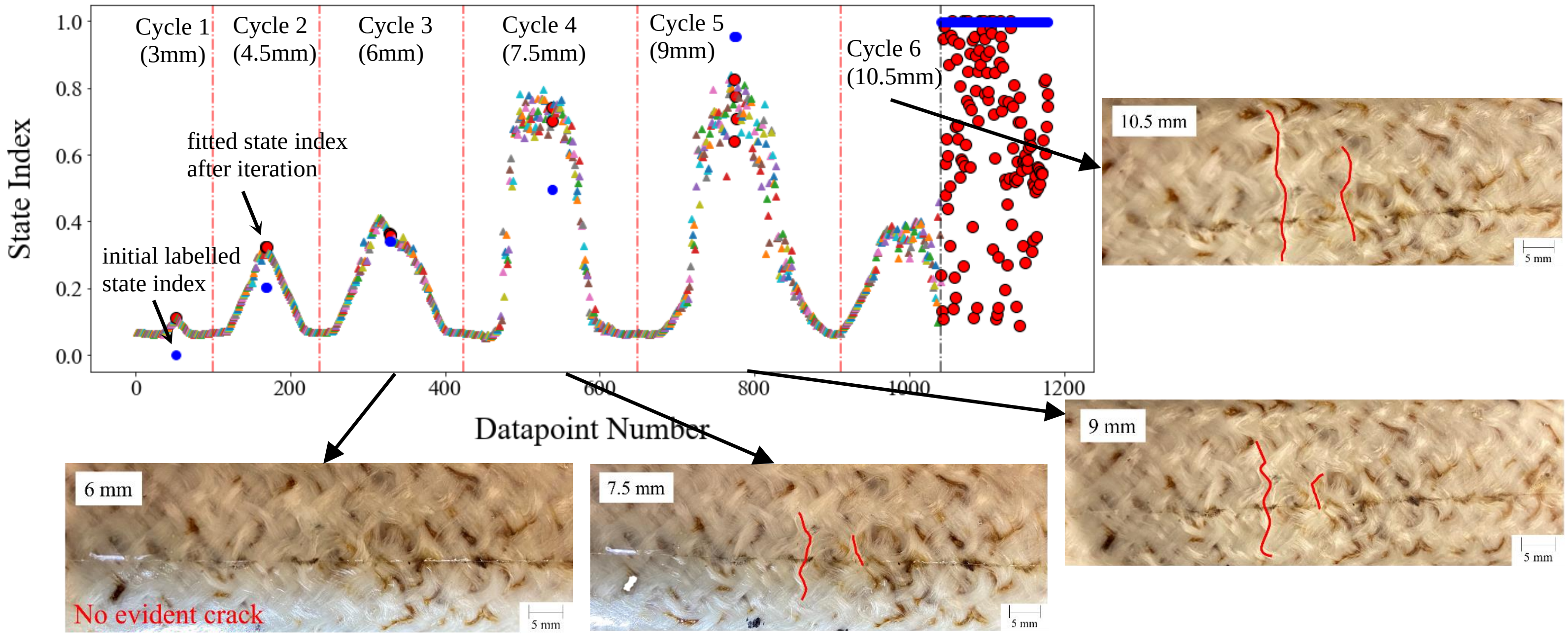


$$C_j = \frac{b_j - \min(b_{1:6})}{\max(b_{1:6}) - \min(b_{1:6})},\ j = 1, 2, K, 6.$$

$$S_{index}(i) = \sum_{j=1}^{6} C_j a_{ij},\ i = 1, 2, \ldots, 1179;\ j = 1, 2, \ldots, 6.$$

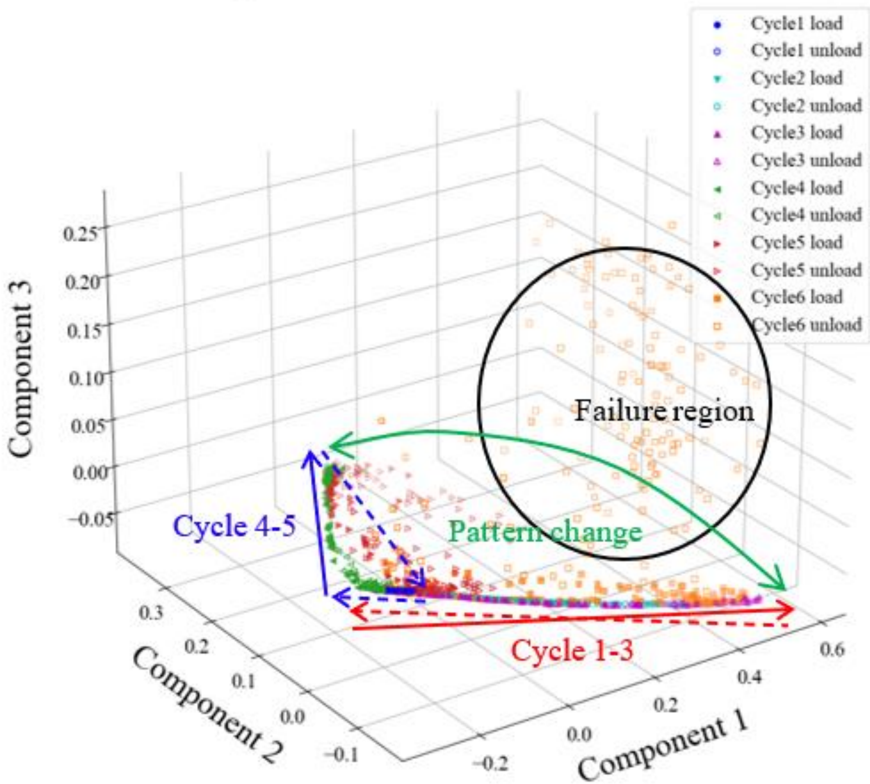


Results – Label spreading and validation



- State index projected by label spreading algorithm: blue points were the state index calculated by the initially given labels; red points were the fitted results of datapoints given by the KNN kernel.
- The images showed the damage happened at the centre of the beam under the loading cell taken by the travelling microscope, with the red lines indicated the crack length.

Results – Damage visualisation and identification in the feature space



- The data components showed a repetitive cyclic behaviour for LC1 to LC3 with the data for both the loading and the unloading cycles lying along the same vector in the component space.
- After LC3, the data showed a significant shift in the pattern change and did not remain the same path as LC1 to LC3. This was an indication of the occurrence of an irreversible damage in the structure. In the unloading process of LC4 and LC5, the data could not recover to the respective cycle even at the ends of unloading cycles.
- For LC6, the data showed random and irregular patterns which potentially due to the DOFS breakage.

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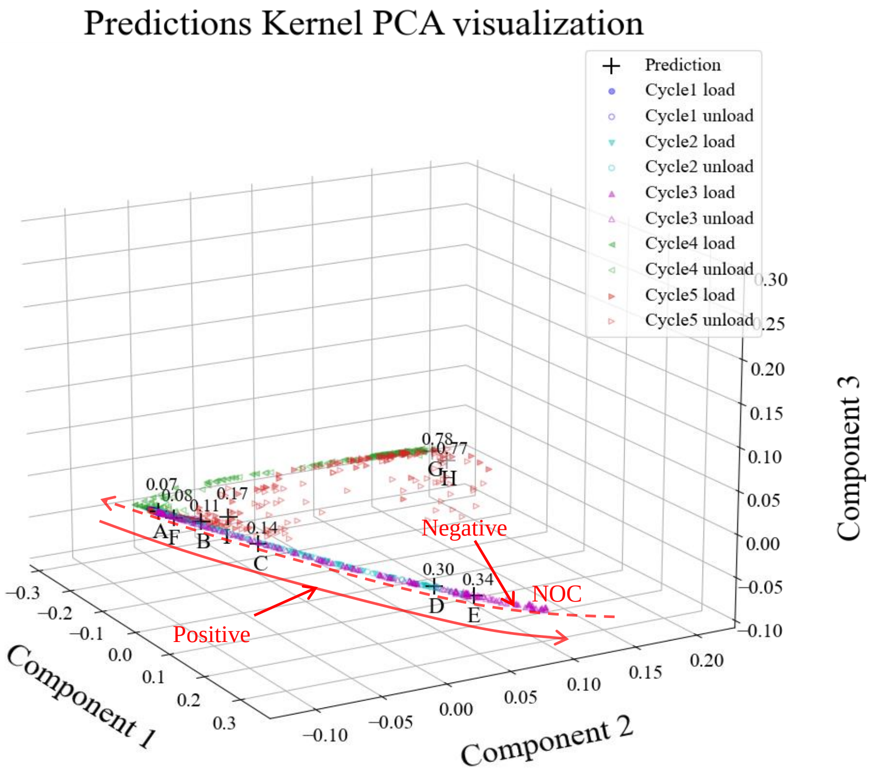
Results – Damage visualisation and identification in the feature space



- A normal operating curve (NOC) was defined along the path of LC1 to LC3, where no damage was presumed.
- If the presence of data followed the positive direction of NOC, and the state index would increase, which indicated that the sample was under loading stage, such as, point A to point B in LC1 and point C to point D in LC2, and vice versa.
- The position of the data in NOC could also be associated with the magnitude of loading, i.e., the positions of data in MDPs were at the furthest position from the initiation, for example, point B was at the furthest position in data obtained from LC1.

Conclusion

- The Distributed Optical Fibre Sensing (DOFS) located with a proximity distance to the damage location has demonstrated the sensitivity of detecting the strain changes within different loading cycles.
- The state indices and labels projected by label spreading algorithm can well fit and corelate with the experimental observations with only one identified artificially labelled datapoint, which demonstrated the feasibility of the proposed methodology.
- By decomposing the labels of datapoints with the KPCA, the positions of datapoints in the feature space combined with state index can be used to verify the presented damage and loading conditions of the sample, which can help to implement structural health monitoring of structures.
- The developed technology can examine the presented damage and load state by learning six progressive cycles. Upon this study, this technology can be exploited to other engineering cases that satisfy the following two requirements: a) damage only occurred and propagated in the specific area of the sample, b) the loads are repeatedly and gradually increasing. In this case, the measured raw data (e.g., strain) would alter continuously in patterns, making it possible to be decomposed to feature space and the pattern change would follow an explicit routine associated with the load magnitude.

Thank you and Questions?

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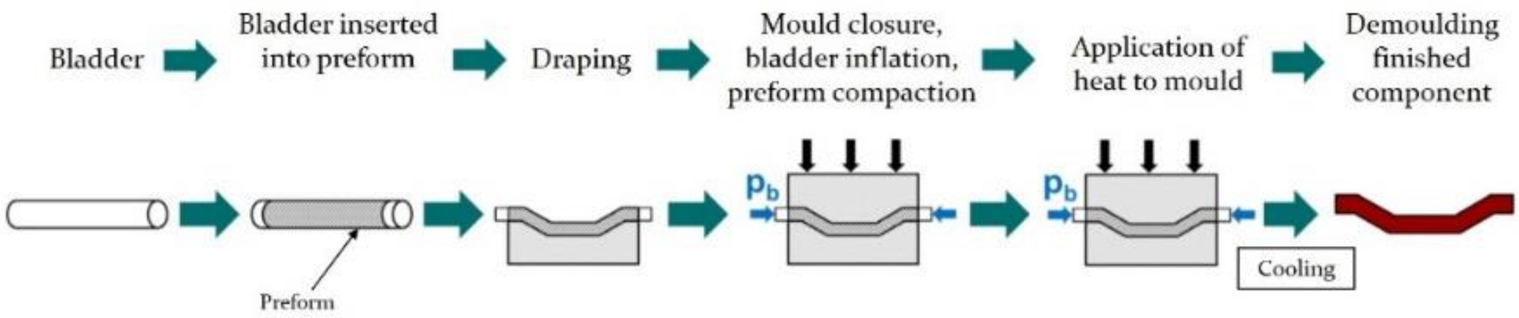
Manufacturing: Bladder moulding



35 mm OD
~500 mm long

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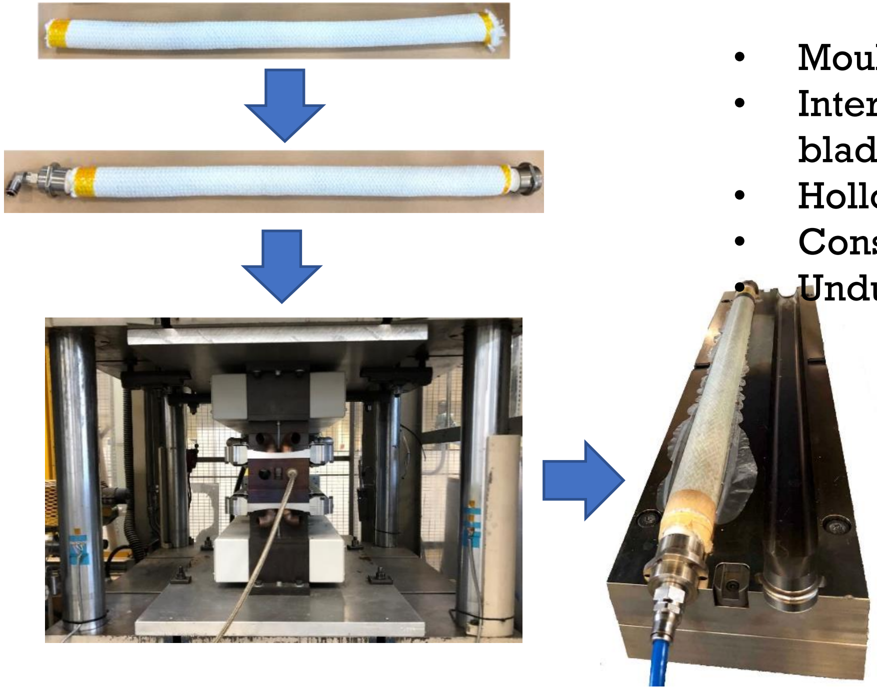
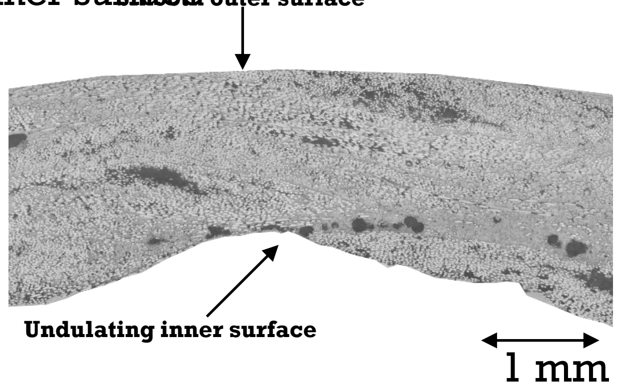
Manufacturing: Rapid variothermal moulding



RVM process[14]

- Moulding in a metallic tool
- Internal pressurisation via silicone bladder
- Hollow circular beams
- Constant outer diameter of 35 mm
- Undulating inner surface



Micrograph of produced beam