Monitoring of composite pipelines using embedded sensors

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Introduction

High strength and low density make composites particularly suited to structural applications, but detecting and monitoring of defects remains a challenge. The use of composites reduces costs by reducing scheduled maintenance compared to non-composite structures. Weight reductions also result in lower operating costs.

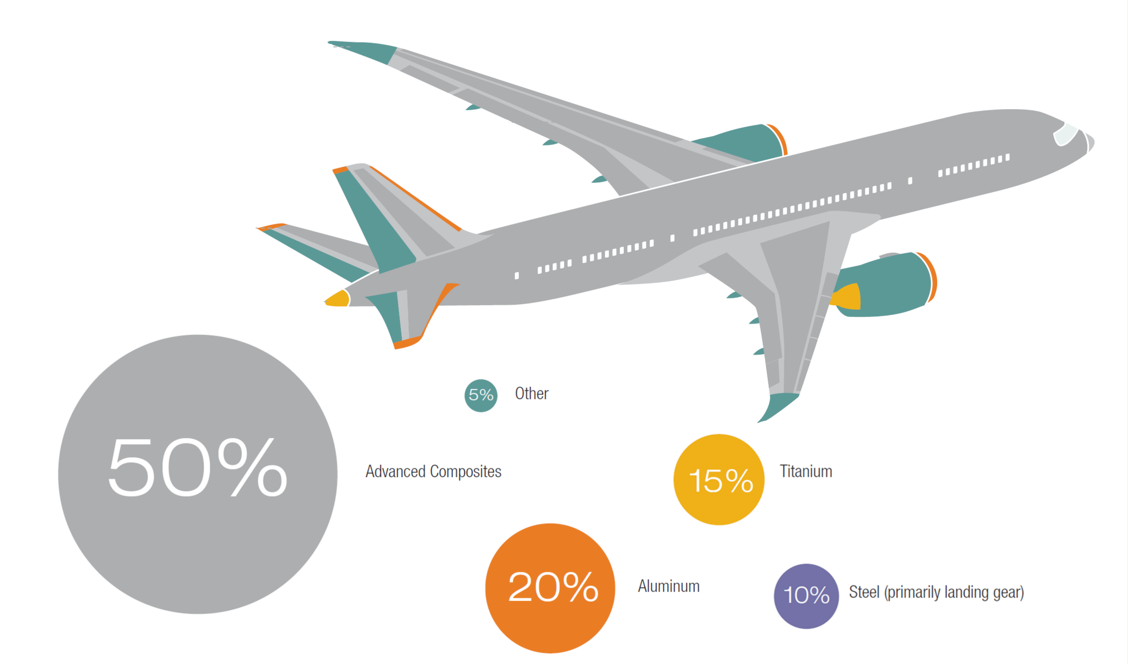

Figure 1: Use of composites in the Boeing 787 Dreamliner

Non-destructive evaluation and structural health monitoring allow analysis and monitoring structures in-situ and in real-time, by the integration of permanent sensor networks (Figure 2).

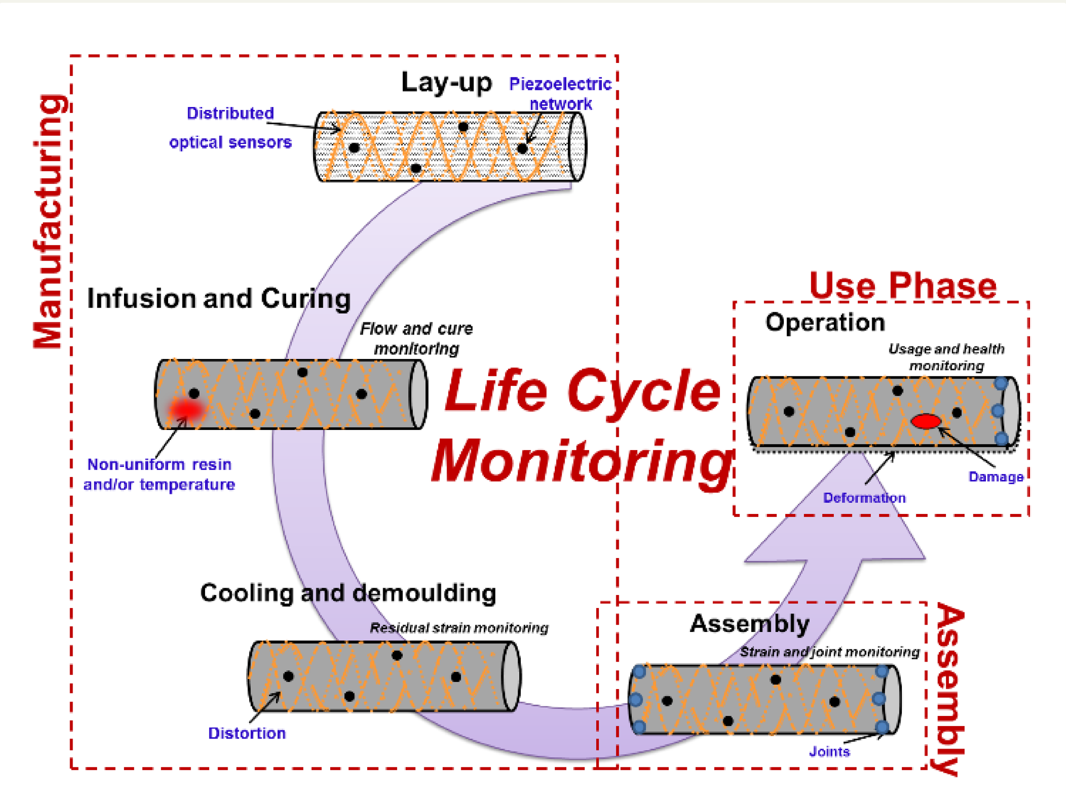

Figure 2: Life cycle monitoring of a composite pipeline

In this work, a distributed optical fibre sensor (DOFS) was embedded through the thickness, and along the length, of a carbon fibre composite laminate, providing three principal sensing regions: 'top', 'middle', and 'bottom' of the laminate. Figure 3 shows the placement of strain gauges and piezoelectric wafer active sensors (PWAS) for measurement of surface strain and detection of acoustic emissions (AE), respectively.

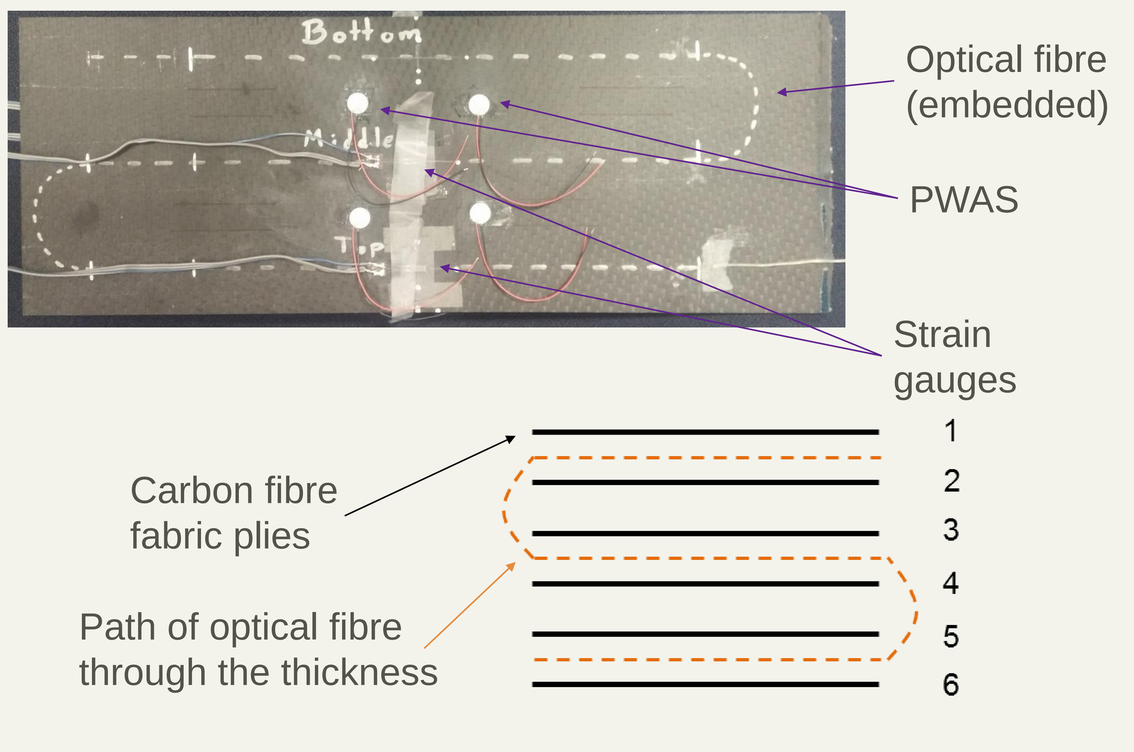

Figure 3: Top view and cross-section schematic of FRP plate with integrated optical fibre, and bonded PWAS and strain gauges

Experimental

Four point bending was conducted on the composite plate (Figure 4). During each of the test cycles the following data was collected:

- AE events recorded by the four bonded PWAS
- Surface strain measured by each of the four bonded strain gauges
- Internal strain data recorded by sensors along each DOFS region

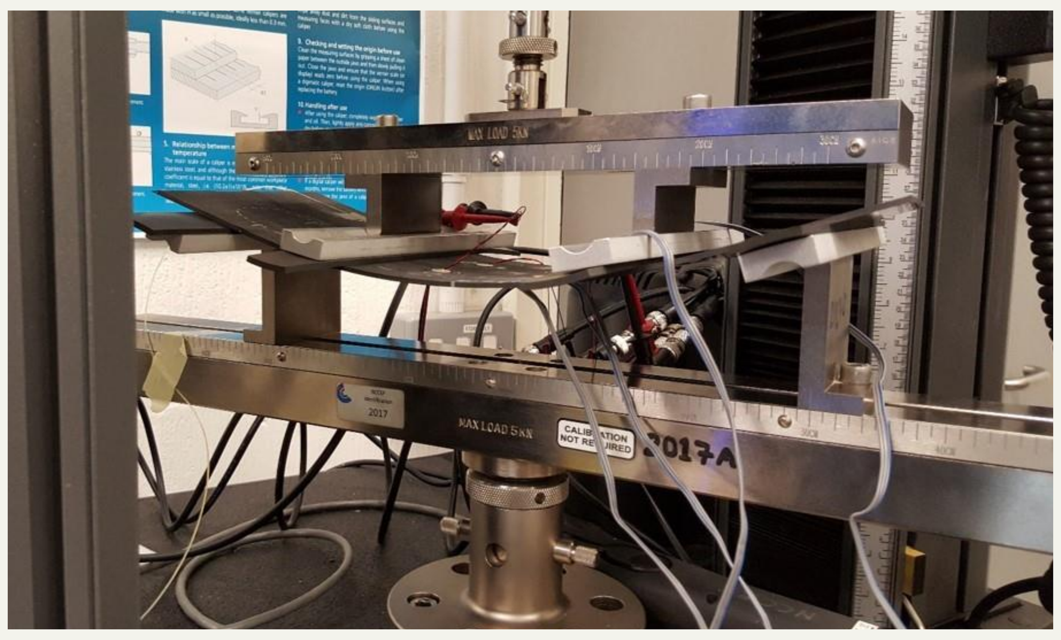

Figure 4: Four point bending set-up

Collection of this data showed a correlation between surface strain and internal strain data (Figure 5), and with the formation and growth of damage during progressive loading cycles (Table 1).

Table 1: Progressive bending cycles

Test	Max strain - as measured by central strain gauge (%)
1	0.14
2	0.14
3	**0.2**
4	0.29
5	**0.4**

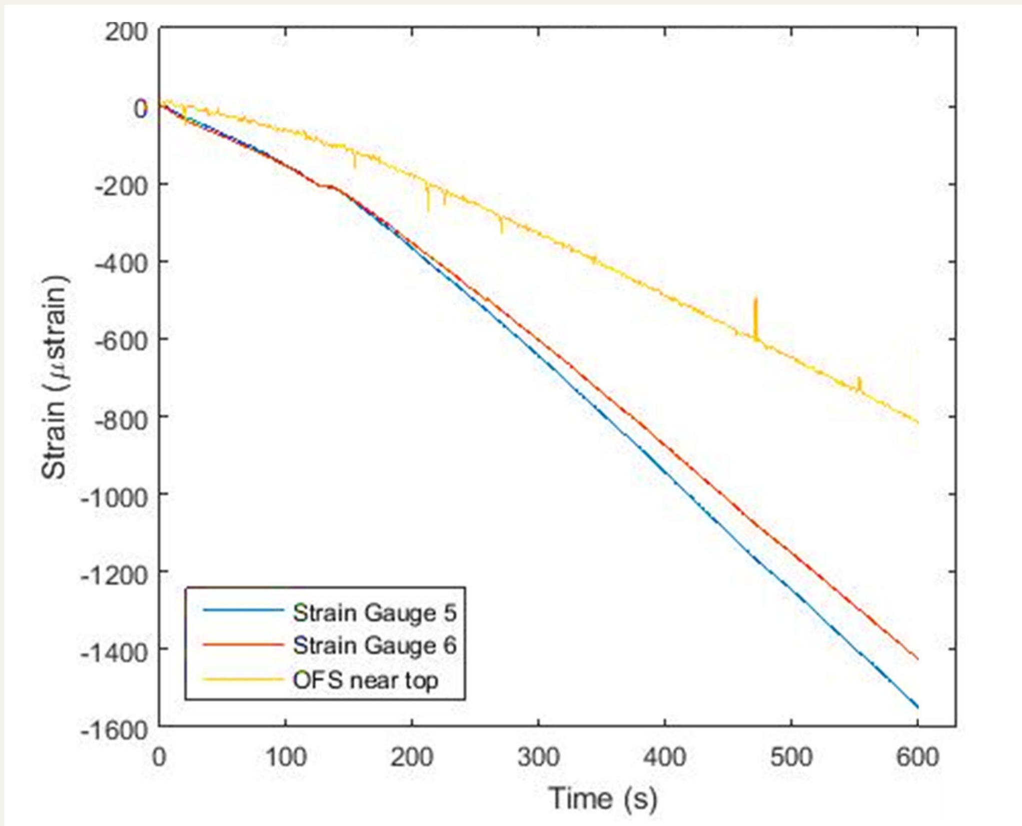

Figure 5: Correlation of surface strain (strain gauges) and internal strain (OFS top sensing region)

Results

DOFS data demonstrates sensitivity through the thickness of the panel. The 'top', 'middle', and 'bottom' sensing regions clearly indicate the development of compressive, neutral, and tensile strain, respectively.

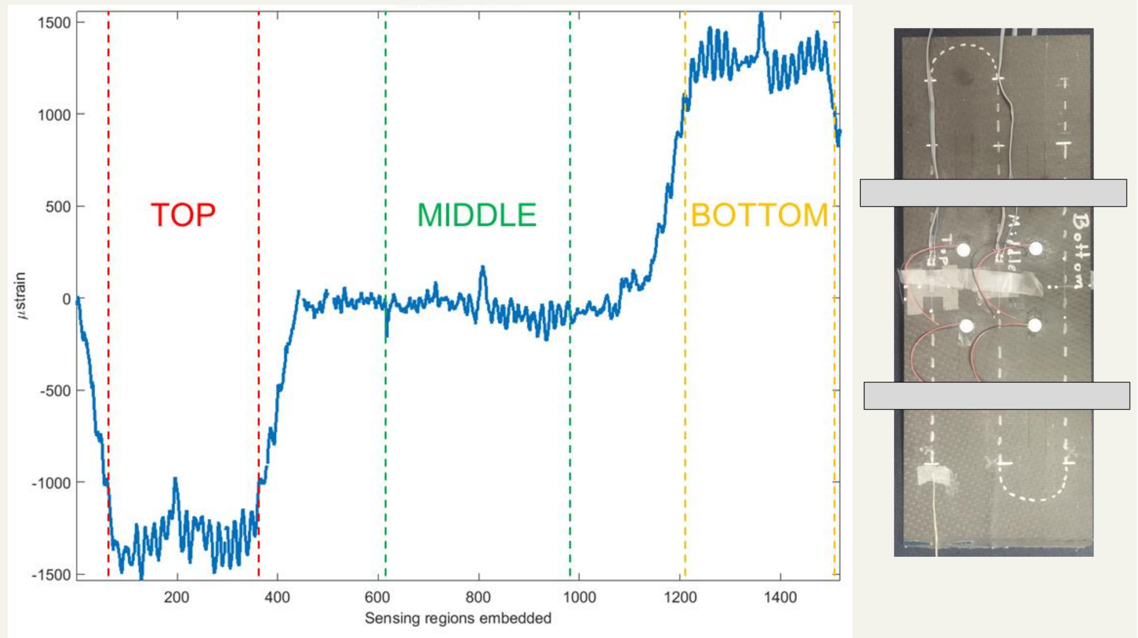

Figure 6: Sensing regions embedded vs. strain - bending cycle 4

Figure 6 shows this strain measurement at the end of cycle 4, where the maximum strain measured by the central strain gauge was 0.29%. A peak in each measurement section indicates a stress concentration, possible caused by a defect formed in the structure during bending.

Acoustic event detection suggests the formation of matrix cracks, with measured amplitudes falling in line with values reported in published literature. Figure 7 shows the amplitude of each AE hit received during progressive bending cycles. High amplitude hits may correspond to the strain peaks observed in the DOFS data.

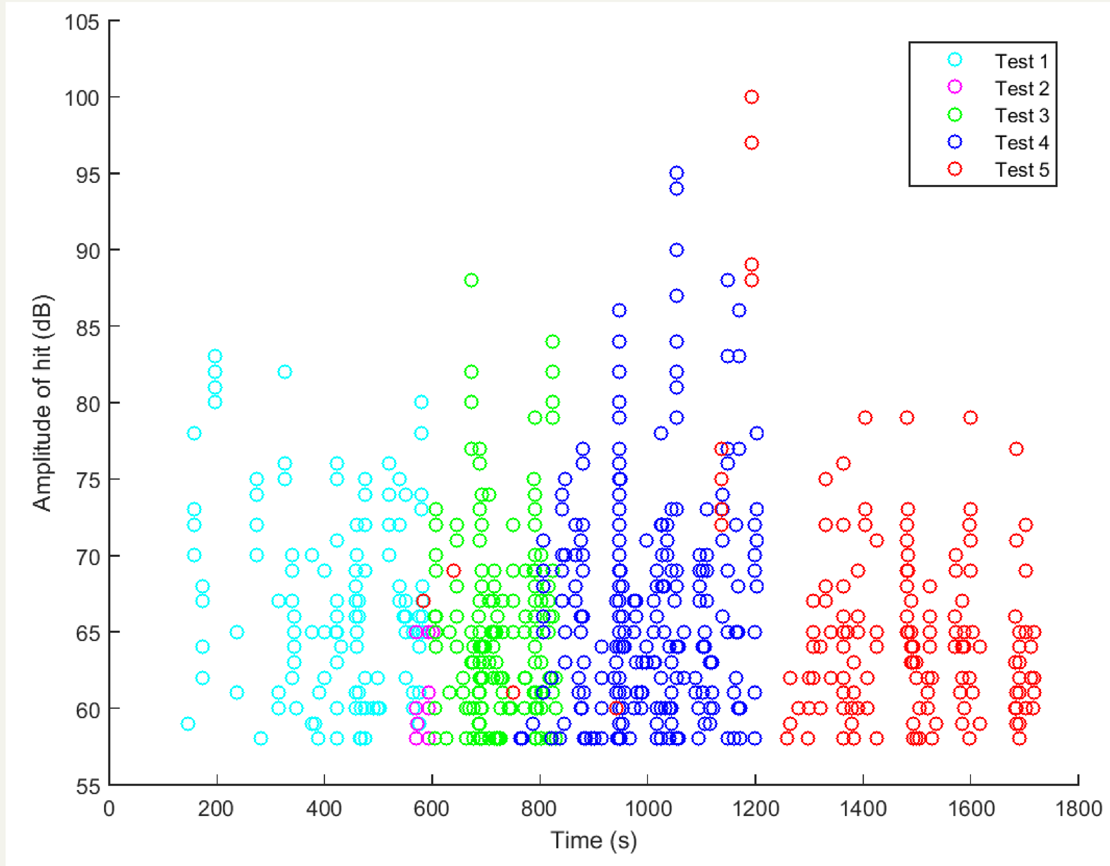

Figure 7: Amplitudes of AE hits during progressive loading cycles

Conclusions

This work has shown promise in the use of DOFS and PWAS simultaneously as part of an integrated sensor network for structural health monitoring of composite structures. The clear distinction of strain development between each of the sensing regions demonstrates sensitivity of the technique. AE signals suggest the formation of matrix (resin) cracks. The ability to monitor the growth of such defects can have significant implications on the advancement of models that aim to accurately predict remaining component lifetimes, while additionally aiding the optimisation of design and manufacturing processes.

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