Early damage detection in composites by distributed strain and acoustic event monitoring

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Abstract. Advances in the development of fibre reinforced polymer composites and their manufacturing techniques have led to their increased use as structural materials. In this study, a composite plate is instrumented with different sensors to enable monitoring during a four point bending. Distributed strain data recorded by an embedded optical fibre correlates well with electrical strain gauges, while acoustic emission data suggests the formation of resin cracks during loading.

Introduction

Composites offer superior corrosion resistance and high specific strength and stiffness compared to metals, while designing anisotropic structures can provide weight reductions. However, there is uncertainty associated with understanding the consequences of out-of-plane damage in composites. Non-destructive evaluation (NDE) techniques are adopted in many cases, but represent significant down-time and labour costs. Attached and/or embedded structural health monitoring (SHM) systems have shown promise in improving the reliability and safety of composites, while reducing lifecycle costs, and improving design and manufacture processes.

Distributed optical fibre sensors. Distributed sensing with an optical fibre sensor (OFS) allows fluctuations in temperature and mechanical strain to be monitored along the length of the optical fibre. This SHM technique uses conventional silica glass optical fibres as continuous strain/temperature sensors with high spatial resolution and the potential to resolve measurements as fine as 1 µstrain and 0.1°C [1,2].

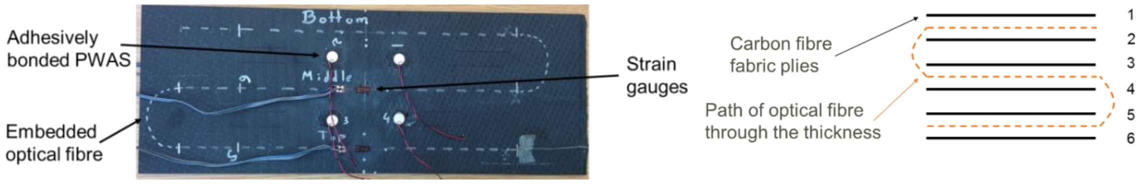

Figure 1. Network of sensors in finished panel (left) and integration of OFS through-the-thickness of the panel (right)

Acoustic emission. Acoustic emission (AE) uses piezoelectric sensors as receivers of waves propagating through the host structure to which they are bonded. The formation and growth of defects in a material causes the release of energy from the defect tip in the form of elastic waves, which is recorded by the sensors. The use of AE for early damage monitoring is well established [3] and four main damage mechanisms have been identified [4,5]: (i) matrix cracking, (ii) interfacial debonding, (iii) fibre pull-out, and (iv) fibre breakage. The amplitude of a received AE signal is linked to the volume/energy of its source, thus matrix cracking and interlaminar cracks (delamination) can be expected to produce signals with low and high amplitudes, respectively. A comparison of results found in the literature is made in our preliminary work [6,7].

Experimental set-up

A single-mode, low-bend-loss, polyimide coated silica glass optical fibre sensor is embedded in a six ply carbon fibre-epoxy composite laminate during fabrication. Three strain sensing regions near the top, middle, and bottom surface of the laminate (Figure 1) allow in-situ, real time strain monitoring in the panel during resin infusion and curing. A comparison between the strain developed during infusion and the residual strain in the panel after manufacture revealed a close relationship between them. This observation can be useful in composites manufacture, since it becomes possible to measure residual (thermal and mechanical) strains which could impact the final material properties. Four point bending is conducted on the plate. Acoustic emission events are collected using four bonded piezoelectric wafer active sensors (PWAS), thus allowing the comparison of strain data with damage formation and growth during progressive loading cycles.

Discussion of results

Distributed strain data demonstrates the sensitivity of the optical fibre through-the-thickness of the panel (Figure 3). The sensing regions clearly indicate the development of compressive, neutral, and tensile strains, while the absolute values are in good agreement with strain data collected by electrical strain gauges. The amplitude distribution of recorded AE hits suggests the formation of matrix cracks in the laminate. Particularly high amplitude hits (90-100 dB), which researchers [6] have previously attributed to fibre fracture, are observed during the fourth and fifth loadings. It is possible that the signals are caused by micro fibre breakage observed due to stress concentration at the tip of a crack/ delamination [9], since the signals are received at levels of strain where fibre fracture would not be expected to occur.

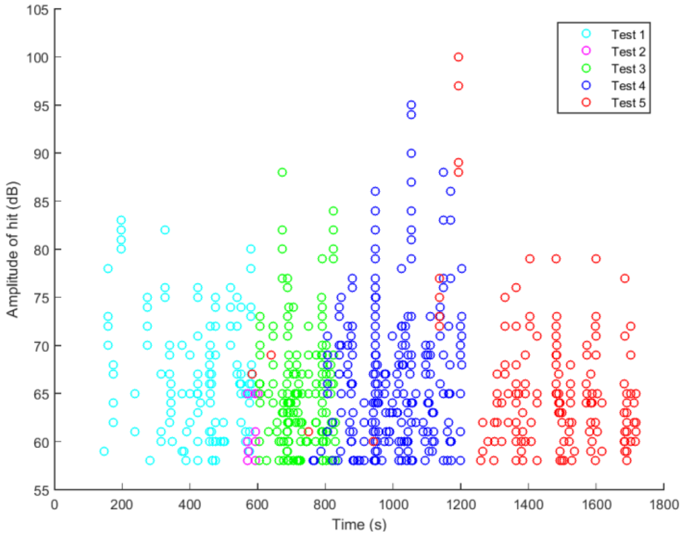

Figure 2. Amplitudes of AE hits recorded during the first five loadings

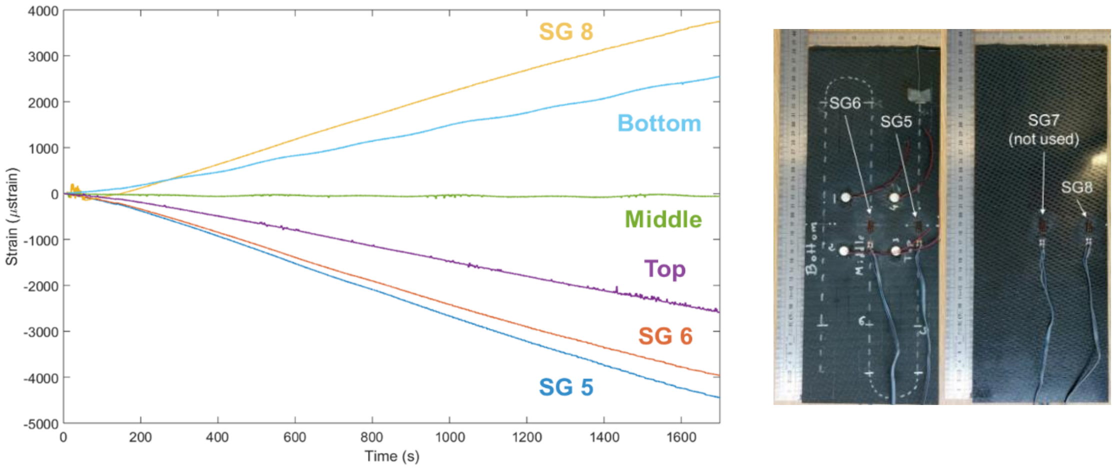

Figure 3. Comparison of strain recorded by strain gauges and OFS during fifth loading

Conclusion

This work has demonstrated the ability to combine different monitoring techniques to glean information about structural damage in a composite material. Further work is required to analyse fully the AE signals, particularly with regards to features of the waveform such as signal duration, peak frequency, etc.

Acknowledgements

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