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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. They 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 techniques are adopted in many cases, but represent significant down-time and labour costs. Attached and/or embedded structural health monitoring systems have shown promise in improving the reliability and safety of composites, while reducing lifecycle costs, and improving design and manufacture processes. In this work, a distributed optical fibre sensor is embedded in a six ply carbon fibre-epoxy composite laminate during fabrication, to give three strain sensing regions near the top, middle, and bottom surface of the laminate, which allow in-situ and real time monitoring of strain development in the panel during resin infusion and curing. Four point bending is then conducted on the plate. Acoustic emission events are collected using four bonded piezoelectric wafer active sensors, thus allowing the comparison of strain data with damage formation and growth during progressive loading cycles. Distributed strain data demonstrates the sensitivity of the optical fibre through-the-thickness of the panel. The top, middle, and bottom sensing regions clearly indicate the development of compressive, neutral, and tensile strain, respectively. The strain values obtained from the optical fibre are in good agreement with strain data collected by surface mounted strain gauges. Acoustic event detection suggests the formation of matrix (resin) cracks, with measured damage event amplitudes in agreement with values reported in published literature on the subject.

Keywords: Acoustic emission; composites; distributed strain; optical fibre; PWAS; structural health monitoring

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1. Introduction

Fibre reinforced polymer (FRP) composites have become more attractive as structural materials in the aerospace and automotive industries, due to the high strength, high stiffness, and low density they offer. Corrosion resistance and weight reduction are the main drivers for the replacement of metal structures by composites. Damage tolerance represents a significant challenge for in-service composite components, however design and manufacture of smart structures capable of monitoring themselves has shown promise in aiding the development of more accurate models for lifetime predictions. The data collected by real-time, in-situ structural health monitoring (SHM) systems can be informative in the effort to prevent premature catastrophic failures. The constitution of composite materials – fibres (in the form of thin layers) and resin – and their manufacture in a layered configuration make them particularly well suited to the integration of sensor networks; this type of integration would simply not be possible with metals. The incorporation of permanent sensors can be useful for nondestructive evaluation (NDE) of a component as well as SHM by interacting with the structure in an active or passive way. SHM systems can also allow monitoring of defects/flaws introduced during fabrication and when the component/structure enters service (Figure 1) [1].

1.1. Distributed strain monitoring

Distributed sensing with an optical fibre sensor (OFS) allows fluctuations in temperature and mechanical strain to be monitored with high accuracy and precision, 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 – typically ~1 mm – and the potential to resolve measurements as fine as 1 µstrain and 0.1°C [2,3]. On passing a narrow band of light through the core of an OFS, Rayleigh backscatter occurs as a result of interactions between the light and silica glass core. Measurement of this Rayleigh backscatter profile provides a unique 'fingerprint' of that OFS. Spectral shifts in the profile caused by temperature/strain fluctuations can be measured. Scaling of the spectral (energy) shift gives distributed measurement of temperature or strain [4]. Losses below 20 dB/km allow for distributed sensing over large distances [5–7]. OFS have been integrated into composite laminates for manufacturing process strain monitoring [8] and damage detection from residual strain measurement [9]. OFS are most commonly bonded to structures, but it is possible to embed them without significantly affecting the damage tolerance of the composite material [10].

1.2. Acoustic emission event monitoring

Acoustic emission (AE) is a passive SHM technique which uses piezoelectric sensors as receivers of waves propagating through the host structure to which they are bonded or integrated. 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 can be recorded by

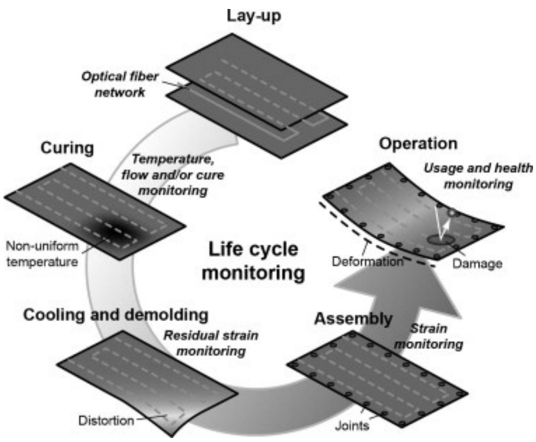

Figure 1. Life cycle monitoring of plate-like structures using permanently integrated sensor networks [1]