Fibre Optic Bragg Grating Sensor Measurements in Composite Materials

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ABSTRACT

Despite the many advantages of composite materials, limited data on their in-service performance continues to restrict their application in aircraft structures. Networks of strain sensing elements offer the potential to perform continuous structure health monitoring, as well as gathering information on structure operating conditions. This paper describes some preliminary findings of an ongoing research programme, which aims to implement embedded optical fibre sensing systems. It is envisaged that these systems will be used for health monitoring of composite aircraft components.

1. INTRODUCTION

Major developments in the field of composite manufacturing technology during the last decade has resulted in rapid growth in the application of these materials in an increasing range of aircraft structures /1/. In these applications composites have already demonstrated significant advantages over metals whilst achieving reductions in structural weight /2/. Currently only limited data exists on the in-service ageing of composites, resulting in conservative designs, high development costs and limited numbers of aerospace qualified materials.

Continuously monitoring the health and performance of composite structures will allow a more efficient use of composites in a greater range of applications. Such systems have the advantage of collecting data on materials and structures whilst they are operating in realistic environments. Measurement (and active control) of composite structure behaviour using embedded optical fibre sensors was demonstrated by Westland and the United Technologies

3.2 Method of measuring at numerous points along a continuous fibre

These point measurements (Fig. 2) are conducted using photo-refractive (Bragg) gratings, written into the fibre using converging ultra-violet laser beams /10/. In order to monitor strain, the peak reflective wavelengths of these gratings are measured. Southampton have demonstrated the capability to produce high performance gratings with short term temperature stabilities in excess of 750°C /11/. Expected sensitivities for Bragg gratings are 10 microstrain.

3.3 Method of measuring between numerous points along a continuous fibre

These line averaged measurements (Fig. 3) involve measuring the optical path difference of light reflected from pre-defined points (eg gratings). This is performed by an OTDR technique where a series of optical pulses is launched into the fibre and the time delay of pulses returning from each point is monitored. Ultra-high resolution OTDR sensors are being built by Southampton University. Expected sensitivities for these sensors are 25 microstrain over lengths of 1 m to 10 m between gratings.

4 DEVELOPMENT OF EMBEDDING PROCESSES

Integrating large numbers of fragile optical fibres into laminates in an industrial manufacturing environment will require significant improvements in fibre embedding techniques. We are concentrating on this aspect of production development and intend to demonstrate our findings later in the programme.

4.1 Optical fibre coating developments

Optical fibres are easily damaged, and require protective coatings to maintain their surface in pristine condition. Optical fibre coatings for telecommunications applications are generally not suitable for embedded sensor applications, and special fibres and coatings need to be developed /12/. Such coatings must be durable and must ensure adequate protection during all stages of structural fabrication and service.

A recent innovation is the use of active coatings, in which the material used to protect the optical fibre may be electrically or optically controlled, for purposes such as ultrasonic flaw detection or active control of structural response /13/.

Processing of thermoset composites typically involves application of pressures of up to 8 bar and temperatures of 180 °C, whilst thermoplastic materials may require application of pressures of about 16 bar and temperatures of 250 - 450 °C. In-service thermal environments may involve temperature fluctuations in the range of -100 °C to +150 °C. Attack of the fibre or coating by substances present in processing and service environments must also be mechanical properties of host composites. We intend to generate design data using several different test techniques, such as those outlined below. It is expected that factors such as the diameter of embedded fibres, and the thickness and properties of coatings, may influence such effects and will be investigated with an aim to developing optimised sensor packages. The effect of environmental ageing on mechanical properties of laminates with embedded optical fibres wil also be assessed.

5.1 In-plane shear

In-plane shear tests (Fig.4a) use tensile loading of ±45° laminates to produce high shear stresses in the region between plies occupied by the embedded sensor. Possible disruption of the reinforcement fibres may cause locally raised shear stresses and hence this test may be useful for studying possible shear enhancing effects of a variety of fibres.

5.2 Tensile and notched tensile

Tensile tests (Fig.4b) produce a relatively simple stress state useful for studying the transfer of stress from the laminate to the embedded optical fibre. Notched tensile tests (Fig.4c) allow study of laminate sensitivity to stress concentrations by including a hole or fastener in the central region of the coupon. Optical fibres may in themselves act to locally raise stresses and hence the cumulative effect of locating them in regions of increased stress is of interest.

5.3 Compressive and notched compressive

Compressive tests (Fig.4d) are expected to be sensitive to possible disruption of reinforcement fibres by embedded optical fibres since possible kinking of reinforcement fibres may increase delaminating stresses. Such effects may be aggravated by locating the fibre in regions of raised stress (Fig.4e) and hence notched coupons will also be tested.

5.4 Fatigue tests

Static tests may give unrealistically high values of laminate properties if, for example, progressive failure of the embedded fibre/host interface occurs during service. Repeated cycling of plain (Fig.4f) and notched coupons (Fig.4g) under various conditions of stress is proposed. It is intended to study the initiation and propagation of possible failure micro-mechanisms by performing static tests after repeated loadings.

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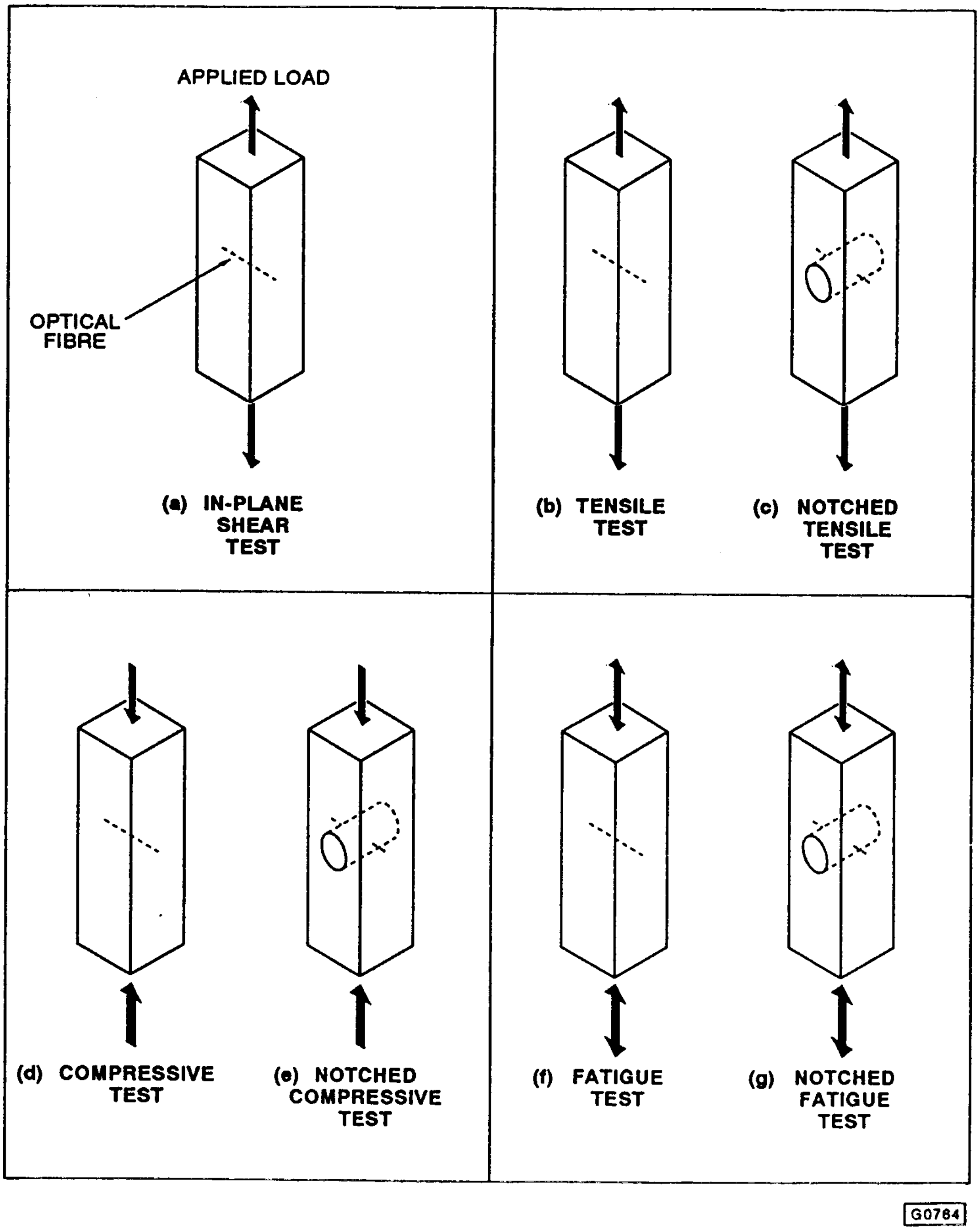

FIGURE 4. MECHANICAL TEST COUPONS

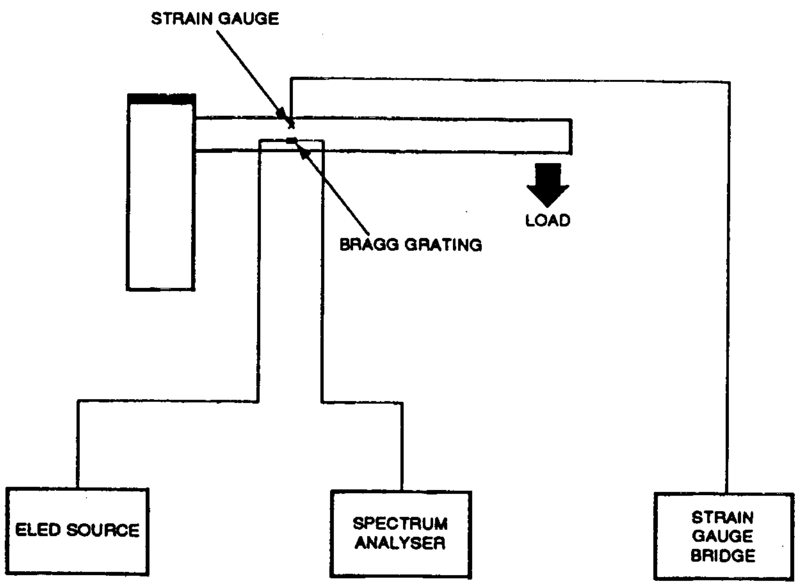

FIGURE 6. GRATING SENSOR MEASUREMENT SCHEMATIC

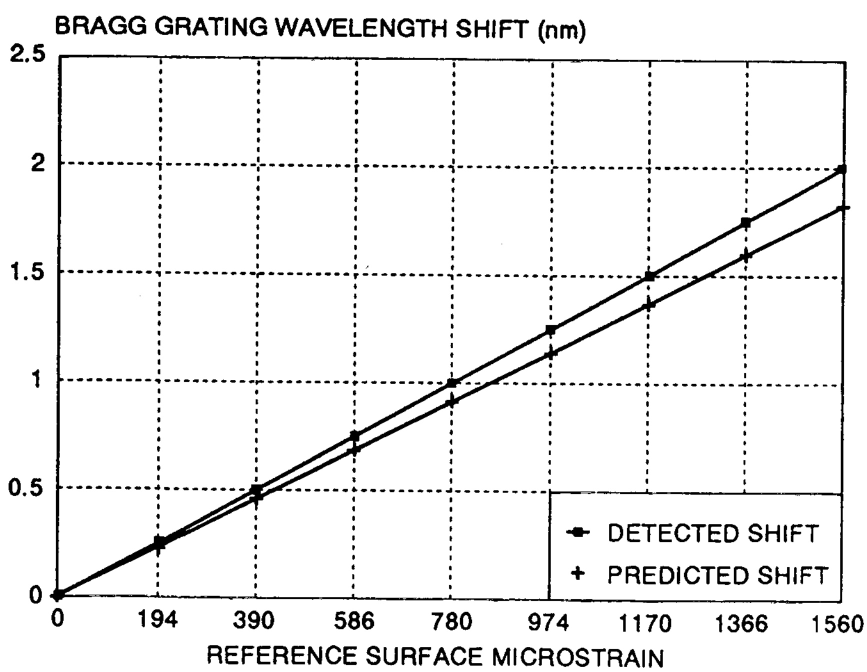

FIGURE 7. GRATING WAVELENGTH vs MECHANICAL STRAIN ON A CANTILEVER BEAM

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