# Investigation of embedded Near Infrared Fibre Bragg Grating (FBG) sensors (830 nm) in structural health monitoring of glass fibre composite structures

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**ABSTRACT:**

The transmitted spectrums of conventional FBG sensors operating in near infrared region (Bragg wavelength ~ 830nm) embedded in E-Glass/Vinylester composite sample were investigated at static and after fatigue loading. Also transmitted waveforms of a FBG attached to a surface of single layer E-Glass/Vinylester composite sample which has a purposely created hole closer to attached FBG sensor were examined in order to understand the FBG response in a vicinity of a void/damage, under static loading situation. As a consequence, some conclusions were made on the sensitivity and durability of the use of FBG sensors fabricated by conventional writing techniques in long term health monitoring system of composite structures.

**Keywords**: Structural Health Monitoring, FBG sensors, Fatigue, Composites

## 1. INTRODUCTION

Glass fibre reinforced plastics (GFRP) composite materials are widely used in many engineering applications such as wind turbines, automotive, marine, aerospace and civil infrastructures because of their excellent strength to weight ratio. The structural components made using composites undergo high fatigue loading situations during their operational lifetime which cause the degradation of the properties of composites such as stiffness and strength. However, the damage mechanics associated with degradation process of composites are complex and not completely understood[1]. Therefore monitoring of damage accumulation is critical for maintaining the integrity of composite structures for uninterrupted operation. For this reason, real-time information inside composite structures is vital for structural health monitoring. There were number of studies on the use of FBG sensors to detect and quantify damage such as matrix cracks and fibre delamination in composites [3-10]. The response of embedded FBG sensors provides local information at the embedded location. Mainly this information consists with local strain and variation of strain along the grating length. The shape of the output FBG signal provides some valuable details about the increase of crack density at the embedded location. However, a greater understanding of the behaviour of FBG sensors is essential before deploying them in health monitoring purposes.

The majority of published work on fibre optic sensors associated with FBG sensors which have wavelengths around 1550nm in the infrared region, the window of transparency for telecommunications fuelling the development of advanced fibre optic based technologies. The work described in this paper details the use of FBG sensors about 830 nm, Near Infrared (NIR) region, to investigate structural response of GFRP composites under static and dynamic loading. Whilst not suitable for telecommunications systems, this wavelength region is more suited to the development of low cost fibre grating based sensor systems using lower cost silicon sources and detectors. In particular we exploit recent developments in spectrometer evolution which has seen the commercial availability of low cost silicon compact silicon spectrometers operating in this region.

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## 2. FIBRE BRAGG GRATING (FBG) SENSORS

Bragg wavelength, $\lambda_B$ , which corresponds to period of gratin $\Lambda_0$ as[3]:

$$\lambda_B = \frac{2n_0\Lambda_0}{k} \tag{1}$$

Where $k$ is the order of the grating and $n_0$ is the refractive index of the core material.
Due to a change of axial strain, $\varepsilon$, there is a change in wavelength (for an isothermal condition)[4],

$$\frac{\Delta\lambda_B}{\lambda_B} = p_e\,\varepsilon \tag{2}$$

Equivalent strain optic $P_e$ of was calculated as 0.793 using the data given in Reference 3, 4.

## 3. EXPERIMENTAL PROCEDURE

A grating was written into a photosensitive telecommunication grade fibre of 125μm clad diameter and 5μm core diameter was fabricated. The grating length is 5mm- 10 mm and the Bragg wavelength 835nm. The FBG sensors were embedded in the middle layer, of 650 g/m$^2$ 0/90 woven roving ply, of [0/90 WR]2$_S$/Vinylester laminate samples as shown in the Figure 1.

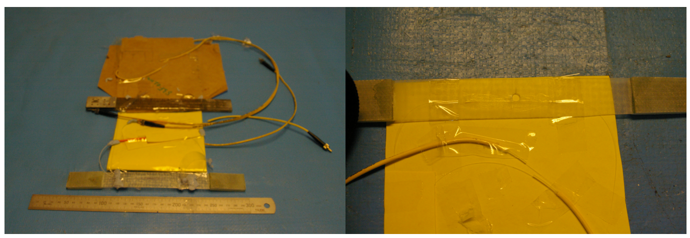


**Figure 1** Test sample configuration- Composite samples which has of embedded FBG in the middle layer (25.3 mm x 5.9 mm and 25 mm x 0.88mm

A samples (25.15mmx 0.88 mm) was prepared with one layer of 0/90 WR/ Vinylester and drilled a hole 5mm dia. in the middle. A FBG sensor was glued on to the sample positioning it closer to the hole.

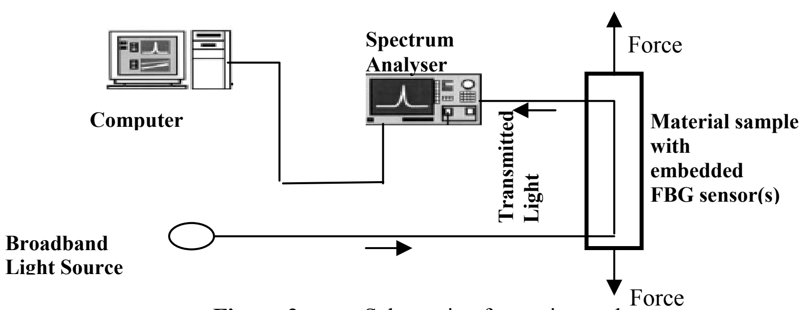



**Figure 2** Schematic of experimental setup

A broadband white light source and an Ocean Optics HR4000 spectrum analyser (resolution 0.02 nm) were used to measure FBG sensor response as shown in Figure 2.

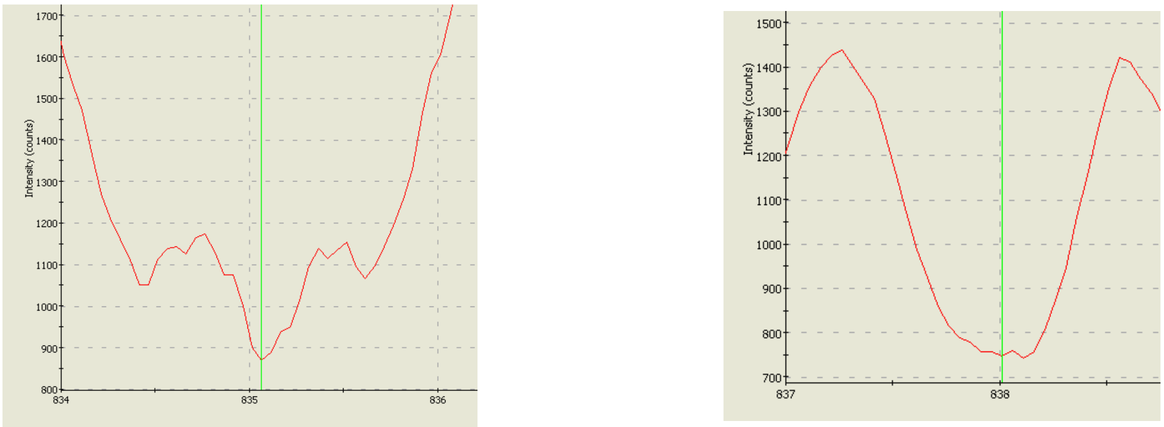
### 3.1 Test procedure

A single layer sample with an attached FBG sensor and the sample with embedded FBG sensor were statically loaded up to 0.5 of Ultimate Tensile Strength (UTS) by steps and recorded FBG sensor response. The sample with embedded FBG sensor was cycled to 100,000 and 50,000 cycles at two stress levels, 36 MPa, and 40 MPa respectively and loaded up to 0.5 UTS and recorded FBG sensor response after each loading.

## 4. EXPERIMENTAL RESULTS AND DISCUSSION

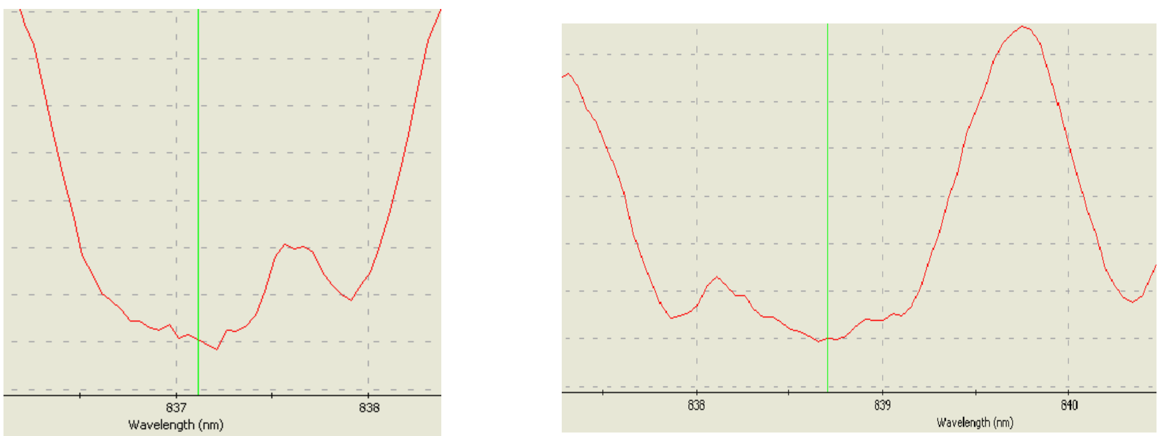
Some of the experimental results are shown in Figures 3, 4 and 5. Figure 3(a), shows the transmitted spectrum at the load level 22 MPa ,and figure 3(b) shows the transmitted spectrum at the load level 40 MPa of the sample with embedded FBG sensor before undergoing cyclic loading. Figure 4(a), shows the transmitted spectrum at the load level

22 MPa ,and figure 4(b) shows the transmitted spectrum at the load level 40 MPa of the sample with embedded FBG sensor after undergone 150000 cycle fatigue loading regime. Figure 5(a), shows the transmitted spectrum at the load level 22 MPa, and figure 5(b) shows the transmitted spectrum at the load level 40 MPa of the single layer sample (5mm dia hole in the middle) with attached FBG sensor.



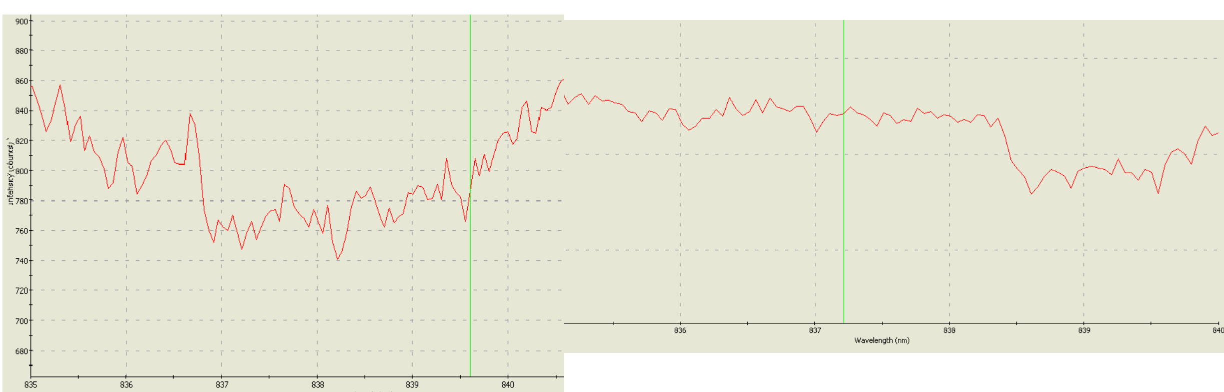

**(a) Load level 22 MPa** **(b) Load level 40 MPa**

Figure 3 Transmitted spectrum from embedded FBG sensor before cyclic loading




**(a) Load level 22 MPa** **(b) Load level 40 MPa**

Figure 4 Transmitted spectrum from embedded FBG sensor after 150000 cyclic loading




**(a) Load level 22 MPa** **(b) Load level 40 MPa**

Figure 5 Transmitted spectrums from attached FBG sensor on single layer sample with a hole in the middle

These observations (figure 3,4) evidently shows that embedded FBG sensors captured the property degradation after 1500000 cycles, as expected. Widening of the shape of the transmitted spectrum of embedded sensor after the fatigue loading is due to the non-uniform strain distribution along the entire length of grating with the increase of matrix cracks inside the material. Figures 5 (a) and (b) shows widening of the transmitted spectrum due the large strain gradient closer to the hole of single layer sample with the attached FBG sensor. There are some significant similarities can be notice in widened spectrums after fatigue loading and at the vicinity of the hole. The stress concentrations along the FBG grating widen the FBG wave length to a wider range about 0.8 nm, which is 1215 micro-strain as predicted by Finite element analysis (FEA) shown in figure 6. Interestingly these observations provide a wealth of information about the widening of spectrum due to accumulated damage.

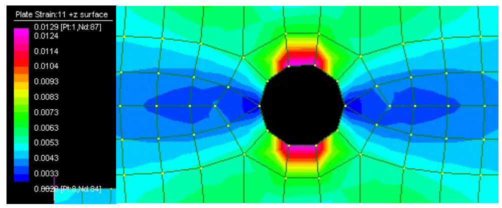



Figure 6 FEA results for the single layer sample with a middle hole

## 6. CONCLUSION

Conventional FBG sensors operating in near infrared region (Bragg wavelength ~ 830nm) were embedded in E-Glass/Vinylester and successfully trialled in a fatigue loading situation. The observed spectrum through an embedded sensor has shown that it captured the damage accumulation inside the composite structure appropriately. The analysed response of the FBG sensor provided a wide range information about damage accumulation, proving FBG's potential in using long –term structural health monitoring of GFRP composite structures.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