Materials Science Forum Vols. 514-516 (2006) pp. 629-632
online at http://www.scientific.net

The Signal Characteristics of the Spectral Response of Bragg Grating Sensor Embedded in Composite Laminated after the Cure Process

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Keywords: Bragg gratings and laminated composite.

Abstract: The objective of this work was to study, understand and evaluate the effect of different geometric configurations of carbon plies, in the reflected wavelength spectrum of Bragg grating structure together with the effect of the recoating process of the sensor. The different possibilities depend upon the orientation and location of the optical fibre relative to the composite reinforcement orientation and the presence/absence of recoating. The material stacking sequence and the cure conditions were are also studied and the influence of the different possibilities was considered. The optical spectrum response obtained by the interaction of the optical fibre with the host material is shown.

Introduction

For many applications in the aeronautics industry, monitoring of structural performance is becoming increasingly important in order to reduce maintenance and inspection costs and enhance efficiency. One of the most attractive sensors to build large area sensor networks has become the fibre Bragg grating (FBG) technology. Despite the fact that FBG sensors have been of considerable interest to the structural health monitoring community for the last few years, many challenges associated with applying FBG sensors in real-world applications have not yet been solved. One of the major issues remaining to be solved is the method of attaching the sensors to the structure to be monitored. It is essential to understand the shape of the optical signal of the sensor and its relation to the actual strain fields in the structure.

Composite materials are increasingly being used as engineering materials in aircrafts, buildings, containers and others structures. They are becoming more and more common because of their specific strength and specific stiffness compared with their metal counterparts, as well as excellent corrosion and fatigue resistance.

The development of smart composite structures involves the integration of sensors, such as optical fibre sensors, into these advanced laminated materials allowing in situ process monitoring and continuous structural health evaluation.

The use of FBGs as embedded sensors in fibre composite materials to provide in situ measurements of strain, temperature, corrosion, vibration and state of cure has been reported by a number of researchers [1,2]. The advantages associated with the use of optical fibre sensors are known and include their immunity to electromagnetic interference as well as their lightweight.

The embedding of FBG sensors in fibre-reinforced composites can result in non-uniformly strained gratings, leading to a distortion of the reflection spectrum [3]. The orientation of the FBG sensor

with respect to the reinforcing fibres in adjacent plies is likely to influence the profile of the FBG spectrum after fabrication. In addition, distortion of the FBG spectrum may also occur as a result of residual stresses generated during the manufacturing processes leading to asymmetric loading of the FBG which, in turn, can result in deformation of the spectrum, leading to reading errors.
In this work, we report an investigation of the influence of the orientation of carbon plies on the final wavelength spectrum shape of an FBG, when the sensor is re-coated with an acrylate coating or without it. Also, some images obtained by optical microscope of a section longitudinal and transversally to the optical fibre, showing the accommodation of the optical fibre to the different arrangements of the materials, are presented.

Fabrication

Several fibre Bragg gratings to be embedded in the composite laminates used in this experiment were fabricated using the following types of fibre: SMF28, simple germanosilicate core (diameter 8.2 μm) and 3 mol% GeO2 cold-hydrogenated at 1 MPa. The FBG were fabricated using a 10 mm length diffractive phase mask illuminated with a KrF laser operating at 248 nm. The central wavelength appears around 1550 nm. Some FBG were recoated with an acrylate coating. The experimental set-up for testing the Bragg gratings embedded in a composite laminate consisted of an erbium-doped broadband source (BBOS) to illuminate the optical fibre through a standard 3 dB coupler. All measurements were recorded by an optical spectrum analyser (OSA), with a resolution of 0.1 nm, connected to a computer (PC) data acquisition system for flexibility in data display, processing and storage.
The composite material used for the fabrication of the laminate plates consisted of pre-impregnated carbon fibre reinforced plastic (CFRP) with a layer thickness of 0.20 mm, in a warp/weft 50/50 configuration (CC206, SEAL), with epoxy resin (ET442). The pre-impregnated CFRP was cut and laid up by hand, placing the optical fibre in the mid-plane of the laminate along the 220 mm direction. The dimensions of the composite laminate were defined as 220×50×0.4 mm^3.

The composite laminate, after lay-up, was vacuum-bagged and placed in an autoclave. The curing cycle of these composites consisted of three stages as follows:

- In stage one, the temperature of the laminate was increased at a 3-5 ºC/min rate to a temperature of 130 ºC, at an external pressure of 0.05 MPa applied.
- In stage two, the laminates were held for one hour at the cure temperature (130 ºC), with 0.2 MPa external pressure applied.
- In the final stage, the composite was cooled to room temperature, inside the autoclave, keeping the 0.2 MPa external pressure.

Results

Several composite laminates with two external layers and one Bragg grating sensor embedded in the laminate were fabricated and monitored by the optical spectrum analyser. Afterwards, to obtain the spectral response result, the composite laminate was cut in section perpendicular to optical fibre and was observed using an optical microscopic.
Fig. 1 and Fig. 2 show the optical fibre embedded in a composite laminate. The orientation of the optical fibre with a FBG was chosen in different position of the CFRP. Fig. 1 presents the optical fibre to perpendicular of the CFRP, in the other hand; the Fig. 2 shows the optical fibre to cross of the CFRP. In each experience, FBGs with and without recoating were embedded in CFRP.

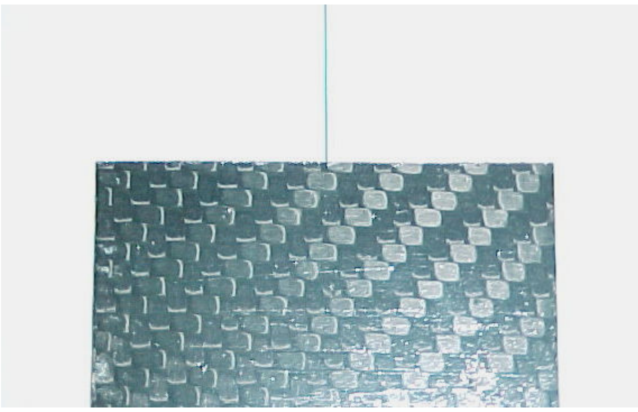

Fig.1 – Photographic of the optical fibre perpendicular to the CFRP.

Fig.2 – Photographic of the optical fibre in cross to the CFRP.

For the CFRP cross-ply specimens shown in Fig. 3 and Fig. 4 some differences occurred. There are some possible reasons for these differences, being one of them, the coating used in the commercial fibres. Fabrication strain during the curing can lead to significant problems, such as interfacial micro-cracking. Also shrinkage may occur during the composite cure cycle. As a result of the cure, the coating on the fibre is no longer round - it has assumed an oval shape. It may be expected that the FBG with recoating, embedded in the composite laminate, with acrylate coating has been damaged [4].

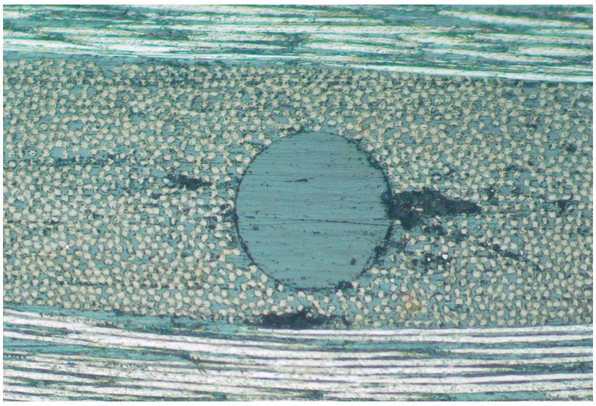

Fig.3 – Optical fibre without recoating embedded in CFRP.

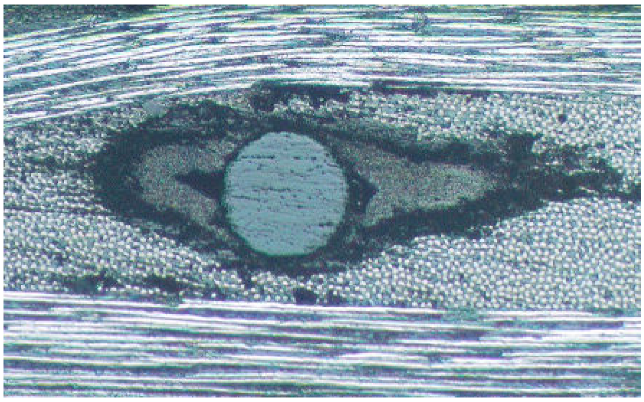

Fig.4 – Optical fibre with recoating embedded in CFRP.

Fig. 5 presents the wavelength spectrum of the FBG without recoating, before and after the cure process. During the cure process the FBG is sensible to the external pressure and during cooling used by the autoclave, the FBG shown has a birefringence in the spectral response [5]. This is due to the pressure applied to the composite laminated and the Bragg grating structure. Two peaks correspond to the slow and fast axis of the optical fibre. The main problem in using this FBG spectrum in conventional interrogation system is due to the fact that the two peaks are very close and cause a misreading in the reflected wavelength. When the FBG is recoated the spectral response is good, ie. the wavelength response is practically the same. The difference between the centre wavelengths before and after cure process results from the deformation of the composite laminated. In cross orientations and without recoating, the spectral response of the FBG is only barely acceptable. Fig. 6 shows the evolution of wavelength spectrum of the FBG with coating in cross orientation to CFRP, before and after cure. The result is acceptable compared with the Fig. 5.

Table 1, shows a summary of the wavelength spectral response condition, when the FBG is with or without recoating for the two orientation of the CFRP.

Table 1 – Resume of the conditions between the FBG embedded in CFRP

Perpendicular FBG to CFRP		**Cross FBG to CFRP**	
Recoating	Without recoating	Recoating	Without recoating
Good	*Bad*	*Good*	*Acceptable*

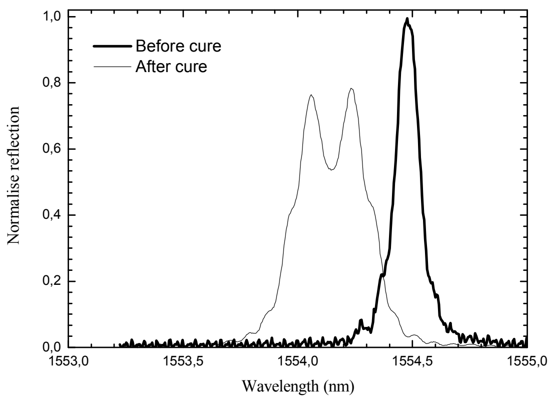

Fig.5 – Wavelength spectrum in optical fibre before and after curing without recoating.

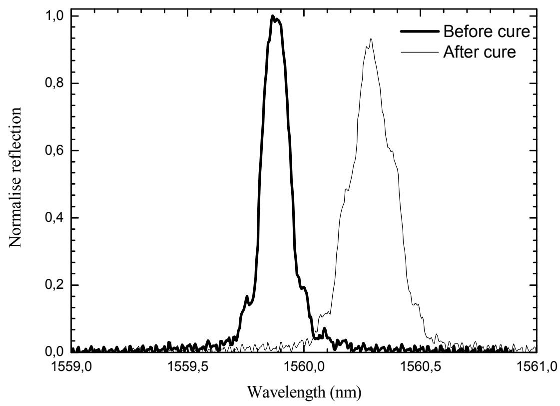

Fig.6 – Wavelength spectrum in optical fibre before and after curing with recoating.

Conclusion

FBG sensors have been successfully embedded in composite materials. An examination of the FBG spectral response before and after the fabrication process has highlighted the effects of the re-coating on the post-fabrication shape of the spectrum. We concluded that all FBGs with re-coating present a good result for embedment in composite material. However, the FBG without re-coating can be applied in specified conditions for monitoring in quasi-distributed sensor, but this configuration needs an interrogation set-up with higher resolution, because the reflected wavelength peaks are too close.

Acknowledgement

The authors would like to thank the Foundation for Science and Technology, and the program PRODEP III – *Medida 5 - Acção 5.3.*

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