Behaviour of optical Fibre Bragg Grating sensor embedded into composite material under flexion

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It is well known that embedding FBG sensors in composite materials and monitoring them when they are placed under constraint is of high interest. We show here that it is possible to embed a relatively long FBG sensor without changing its spectral properties and to follow its evolution (Bragg wavelength displacement and spectral shape) when the sample is subject to different flexion configurations (3 and 4 points bending). The obtained results are compared to simulations. A good agreement is observed, which is promising to measure the distribution of the strain within a composite material.

Introduction

Since their discovery in 1978, FBGs have demonstrated their high utility and reliability in the sensing domain due to their light weight, compactness, high mechanical and corrosion resistance and immunity to electromagnetic interference [1]. During the last decade, composite materials have also been studied with a great interest. They indeed provide a high mechanical resistance coupled with a small weight comparatively to metallic material [2]. These features make them very useful in domains such as in green energy production, aircraft, and railway industries.

In this context, it seems obvious that to embed FBG sensors in composite materials and to monitor them when the material is placed under constraint is of high interest, the final target being to obtain a structural health monitoring allowing to predict failures and to reduce costs maintenance. A lot of works have already been accomplished to limit the deformation of the FBG spectrum after its embodiment [3] or to reduce its effects on the mechanical properties of the composite material [4].

In this work, we want to retrieve the values of the strain applied along the FBG thanks to its spectrum and knowing the type of applied bending. To reach this goal, the first step was to embed a relatively long FBG (12mm) into a composite material sample without spectrum deformation. A reconstruction algorithm is then applied to retrieve the parameters of the FBG before any flexion is introduced. Some found parameters (length and index modulation) will be fixed during simulations. This sample is then tested under different loading conditions (3 and 4-points bending) and deformations of the FBG spectra were observed. By modifying some parameters (initial strain, slope of the strain...) of realistic applied strains corresponding to the type of applied bending, we reconstruct the FBG spectra measured. The shape of the strains retrieved by this simulation is used to retrieve the position of the FBG in the composite material.

Realization of the composite material sample

A few samples have first been processed by means of an adapted filament winding technique on a triangular mandrel. The resulting specimen is an epoxy matrix embedding nearly parallel reinforcement carbon fibres. The winding process can be temporarily interrupted in order to incorporate FBGs at desired locations *(Figure 1)*. To improve the compaction of the product, a radial compression is applied on the material before curing. After curing, the triangular-shape composite is cut to obtain three different samples.
The FBGs were written into hydrogenated low macrobending sensitive singlemode fibre by means of an excimer laser emitting at 248nm through a 1070nm-period uniform phase mask. After inscription, the FBGs were recoated. The FBG length is around 12mm.

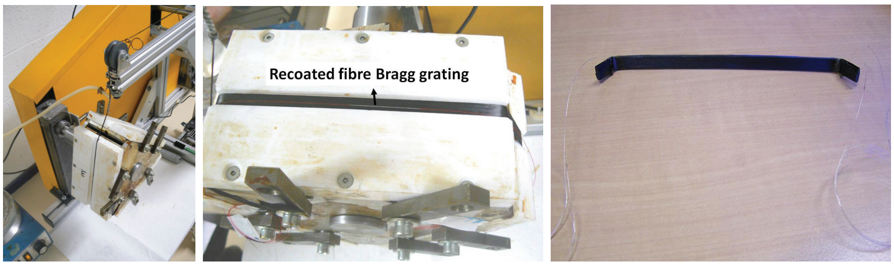


Figure 1: *Start of the winding (left). FBG placement (middle). The final sample (right).*

Interrogation set-up and tested bending configurations

The set-up to interrogate the FBGs is presented in *Figure 2(a)*. It is composed of a broadband optical source and an optical spectrum analyzer to observe the spectra of the sensor. An optical circulator is used to direct the reflected signals to the spectrum analyzer.

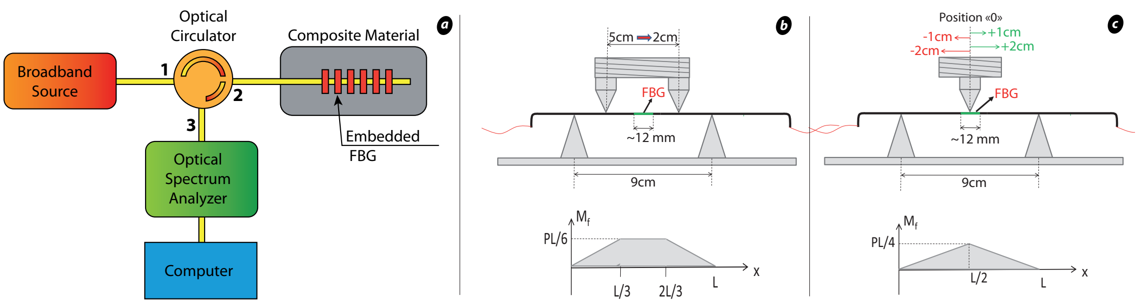
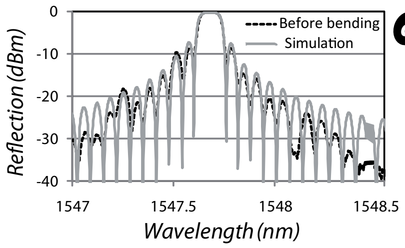


Figure 2: *Interrogation set-up (a), bending types and moment shapes : "4-points" (b) and "3-points" (c)*

The sample was tested under two different configurations. In *Figure 2(b)*, the specimen is under a 4-points bending with a variable distance between the central support points. *Figure 2(c)* presents the same specimen tested under a 3-points bending with a central support point placed at different positions. We also present the shape of the moment when the support points are at equal distance (in the "4-points" bending) and when the third support point is centered with regards to the two others ("3-points" bending). From the theory of solid mechanics [5], the strain (ε) is linearly related to the moment (M_f) and so we can expect to obtain different FBG spectrum deformations as a function of the support points positions.

Simulations and results

Figure 3 presents the experimental and simulated curves of the FBG after embedding and before bending tests. The table summarizes the parameters used for this simulation. For the rest of our simulations, we have fixed the grating length and the index modulation. *Figures 4 (a) and (d)* present the experimental and simulated curves for two "4-points" bending configurations. The reconstruction of the FBG spectra was realized by adjusting the parameters – initial strain ($\varepsilon_{init.}$), value of the strain slope and length of the slope (L_c) – of a known strain shape corresponding to the applied bending due to the linear relation between ε and M_f. The distribution of the strain applied along the FBG to obtain the better matching between the experimental and simulated curves are presented in *Figures 4 (b) and (e)*. The retrieved shape of the strain applied along the FBG can be used to find its position inside the sample. *Figures 4 (c) and (f)* present a global view of the moment along the sample and the supposed position of the FBG for each configuration. *Figure 5* presents the same kind of results as the ones shown in *Figure 4* but in two "3-points" bending" configurations.



b

FBG Length :	12.7 mm
Index modulation :	1.13 10-4
Step of the grating :	534.755 μm
Refrective index of the core :	1.45
Refractive index of the cladding :	1.445
Core radius :	4.1 μm
Cladding radius :	62.5 μm
Effective refractive index :	1.447082

Figure 3: *(a) Experimental and simulated FBG spectra, (b) Simulated FBG parameters.*

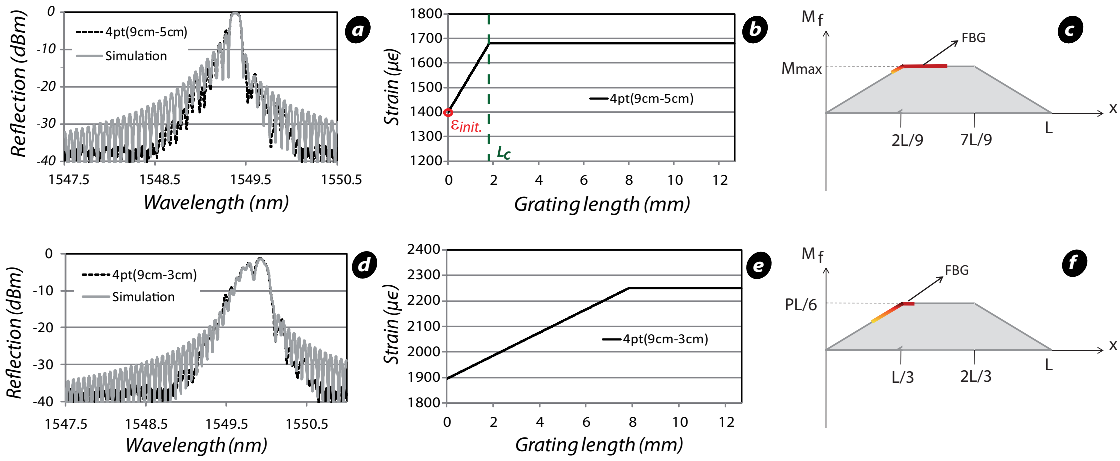


Figure 4: *"4-points" bending configurations: Experimental and simulated FBG spectra (a,d); Strain applied along the FBG (b,e); Schematic moment representation along the sample (c,e).*

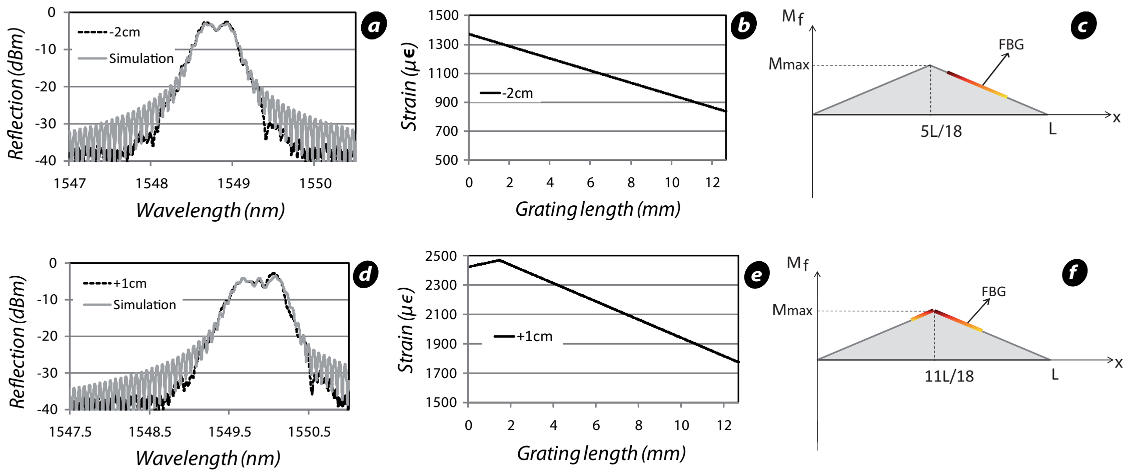


Figure 5: *"3-points" bending configurations: Experimental and simulated FBG spectra (a,d); Strain applied along the FBG (b,e); Schematic moment representation along the sample (c,e).*

Conclusion

We have demonstrated our capability to embed FBGs sensors in composite material without spectrum deformation. The specimen was tested under 3- and 4-point bendings. We have reconstructed the FBG reflective spectra by modifying only the strain and thus the step and the effective refractive index of the grating along the FBG. The results are in agreement with the theory, showing that embedded FBGs can provide a good predicting tool for composite material failure.

Acknowledgement

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References

[1] J. Canning, Fibre gratings and devices for sensors and lasers", *Laser & photonics reviews*, vol. 2, pp. 275-289, 2008.

[2] P.K. Mallick, Fiber-Reinforced Composites: Materials, Manufacturing, and Design, third Edition. CRC Press, 2007.

[3] D.H. Kang, C.S. Hong and C.G. Kim, "Characteristics of Fiber Bragg Grating Sensors with Various Grating Lengths embedded in Composite Materials", *Key Engineering Materials*, vol. 321-323, pp. 152-155, 2006.

[4] K. Satori, K. Fukuchi, Y. Kurosawa, A. Hongo and N. Takeda, "Sensory Phenomena and Measurement Instrumentation for Smart Structures and Materials", in *Smart Structures and Materials*, 2001, pp. 285-294.

[5] W.B. Bickford, Mechanics of solids: concepts and applications, Irwin, 1993, p.491.