Part 11:

Fibre Bragg Grating type sensors in composites

Introduction

Recent studies have shown that Fibre Bragg Gratings are well suited to studying the mechanical behaviour of composites [1]. A Fibre Bragg Grating is a small segment of optical fibre with a core of germanium doped silica which gives a periodic and permanent perturbation of the refractive index. An FBG acts like a selective wavelength mirror, reflecting a particular wavelength (**Fig. 1**), called a Bragg wavelength (λ_B) .

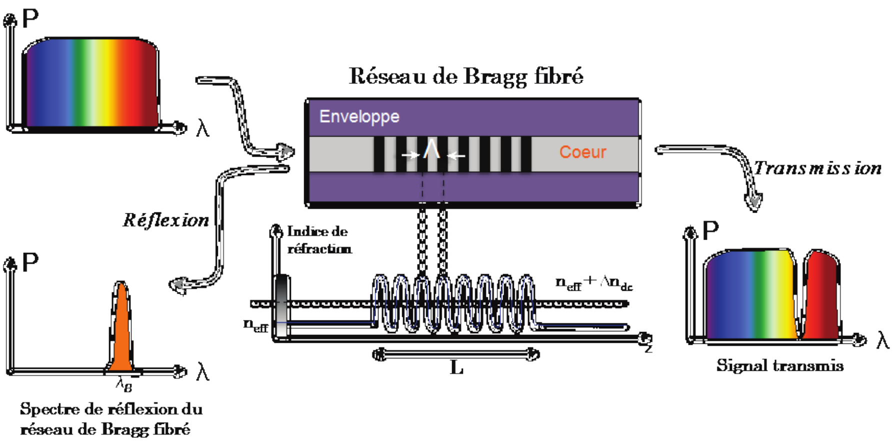

Figure 1 - Fibre Bragg Grating and spectral effects

This Bragg wavelength is proportional to the (Λ) "period" and the effective refractive index of the fibre core (n_{eff}). Thus, any changes to these parameters moves the Bragg wavelength proportionately.

In fact, monitoring its spectral displacements allows you to trace the inductor parameters, such as temperature or deformations suffered locally by the fibre (**Fig. 2**).

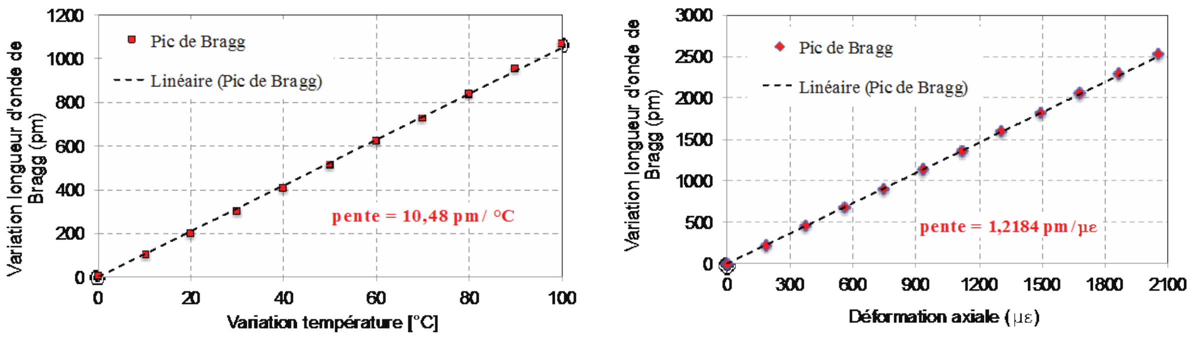

Figure 2 - On the left: Change in Bragg wavelength depending on temperature. On the right: Change in Bragg wavelength depending on deformation [2]

Of course, the use of Fibre Bragg Grating sensors depends on using specific, portable, integrated measuring instruments, based on delicate spectral analysis.

Serving as both reinforcements and embedded gauges subject to a non-uniform deformation field, they give, for example, a direct and non-disruptive power measurement. Their use also seems promising for the systematic study of the fibre/matrix interface and detecting damage in composites.

The major advantage of Fibre Bragg Grating sensors lies in the fact that the information detected is directly coded in the wavelength, which is an absolute parameter. The output does not depend on the level of total light; transmission and coupling losses or optical source power fluctuations have no influence. This is an important aspect when considering long term land measurements. In addition, the wavelength coding information also facilitates sensor multiplexing [3]. This allows for several sections of sensors to be distributed on one single optical fibre, by assigning each sensor to a different portion of the light source spectrum available (**Fig. 3**).

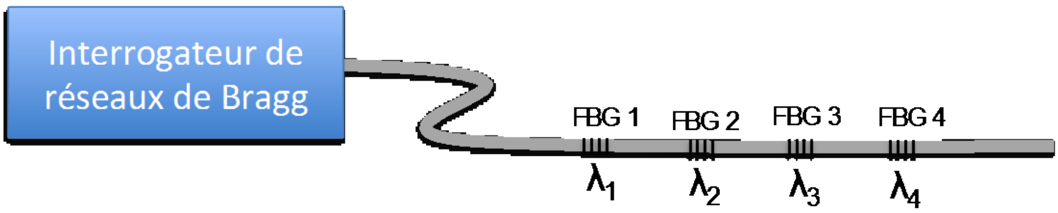

Figure 3 - Wavelength multiplexing with Fibre Bragg Grating sensors

Embedding FBGs in composite materials

For structures using composite materials, it is often necessary to measure the mechanical properties in different parts of the structure. Placing a sensor at each point required quickly creates a problem with congestion and wiring (**Fig. 4**).

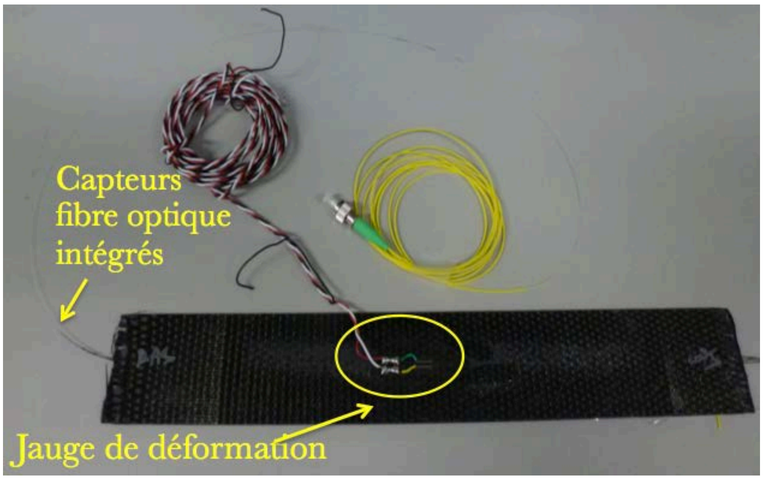

Figure 4 - Comparison between a strain gauge and an optical fibre comprising several Bragg gratings [2]

It is therefore appropriate to move towards distributed or quasi-distributed measuring systems. These consist of passing a single optical fibre through all the measurement points and using a single sensor on the end. When we measure an external parameter continuously along the fibre, we are talking about distributed measurement while the term "quasi-distributed" is used when the measurement points are discretely distributed along the fibre. The aim of embedding Fibre Bragg Grating sensors in composite materials, although this also applies to other materials, is to obtain a form of structural health monitoring or SHM. This means that damage can be predicted and maintenance costs can be reduced while guaranteeing the same level of security.

Optical fibre is very small (external diameter 125 to 250 μm) and very light with variable geometry. By its very nature, it is a continuous and tiny glass fibre, which is, in principle, perfectly adapted to being incorporated in fibre-reinforced composite materials without any significant negative influence on their mechanical properties. Figure 5 shows some stages in the manufacturing process of carbon fibre composite samples, using the stratification method with manual impregnation. During stratification a fibre optic sensor is placed between two layers of fabric.

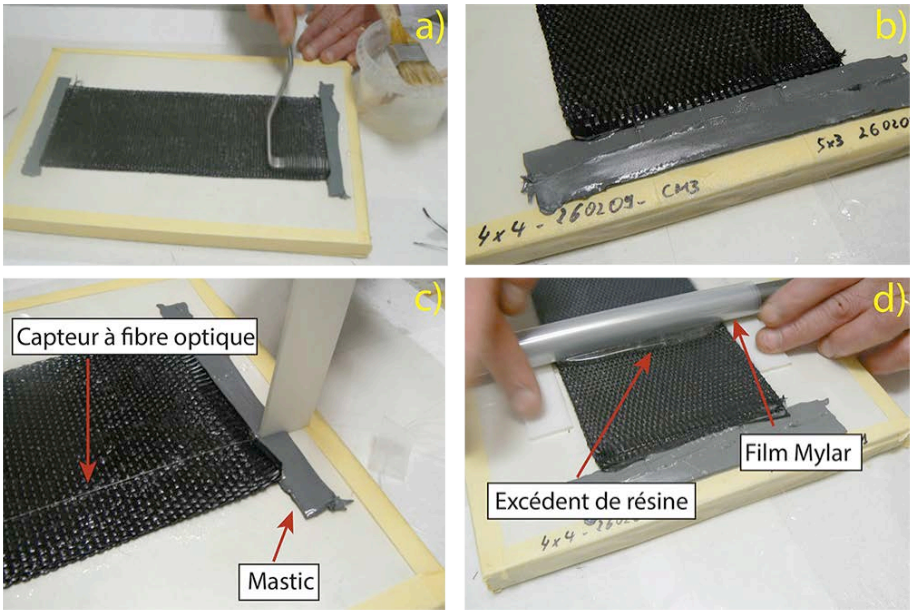

Figure 5 - The different stages of preparing a composite sample. a) Using the bubble removing roller; b) View between two layers of fabric; c) Placing the fibre optic sensor; d) Placing the Mylar film [2]

However, a number of conditions must be met if you are thinking about using optical fibre as a sensor with construction materials [4].

Optical fibre, by its very nature, is extremely fragile (particularly when it is bent), which makes it difficult to manipulate. It must be embedded and connected very carefully.

However, optical fibre can withstand high temperatures and pressures; two important characteristics of several manufacturing processes for composite materials. In addition, it is (or it can be with the help of suitable cladding) relatively corrosion and fatigue resistant.

Because optical fibre is a passive dielectric component, it can be used safely without risk of sparks and furthermore it does not form an electrical conductor on or in the structure. This can be important for aeronautical and space applications where the risk of electric shocks like lightning mean that conductive paths must be eliminated. Its signal is completely immune to electromagnetic interference and it is not necessary to add costly and cumbersome shielding in places where there is electromagnetic radiation (e.g. power plants). Optical fibre can be used as a sensor and can carry signals. In addition, the development of applications for sensors benefits from progress in telecommunications and optoelectronics, which means components are continuously being improved and costs are falling.

Using optical fibre as sensor can cover a very wide range of measurement parameters ranging from mechanical deformation to pressure, temperature, humidity, corrosion and the concentration of gas.

The full detection system must be robust and must have an all-fibre design in order to minimise disruption to the host material and to give a stable signal. It is also preferable to use a single optical fibre with one single access in order to facilitate connection and installation. The sensor must make absolute measurements, so that monitoring is not affected if connections or measurements are temporarily interrupted. The sensor should, preferably, measure at one point or in a small area, and the signal must be directly and linearly linked to the deformation. An option for sensor multiplexing is desirable so that several critical areas of the structure can be monitored at the same time. The sensor must also be sufficiently sensitive and must provide reproducible measurements, with a sufficient dynamic range. Finally, the sensor must be suitable for mass production at a reduced cost.

A solution of the future

Structural health monitoring of structures means that damage can be predicted and maintenance costs can be reduced while guaranteeing the same level of security. Embedding Fibre Bragg Grating sensors in composite materials seems to be a solution for the future or at least complementary to what is already on the market.

Figure 6 illustrates the life cycle of a composite structure (from manufacturing to commissioning) in which the fibre optic sensors are embedded in order to monitor changing deformations and constraints within the part itself

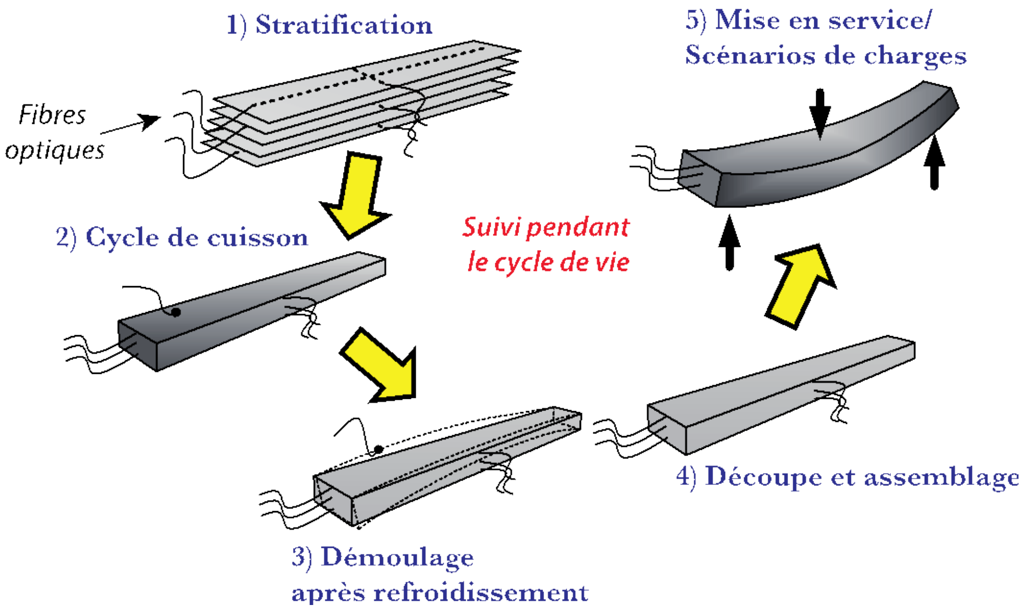

Figure 6 - Schematic diagram showing how the life cycle of a composite structure is monitored using embedded fibre optic sensors where internal deformations are monitored from when parts are manufactured until they are commissioned [5].

Figure 7 highlights the second part (Baking cycle) of figure 24. It shows how the characteristics of the Bragg Grating change (the loss dependent on polarisation [6]). From this, it is possible to monitor changes in the different stages of the manufacture of the composite, to see that polymerisation is complete and to try other baking cycles in order to reduce residual stresses.

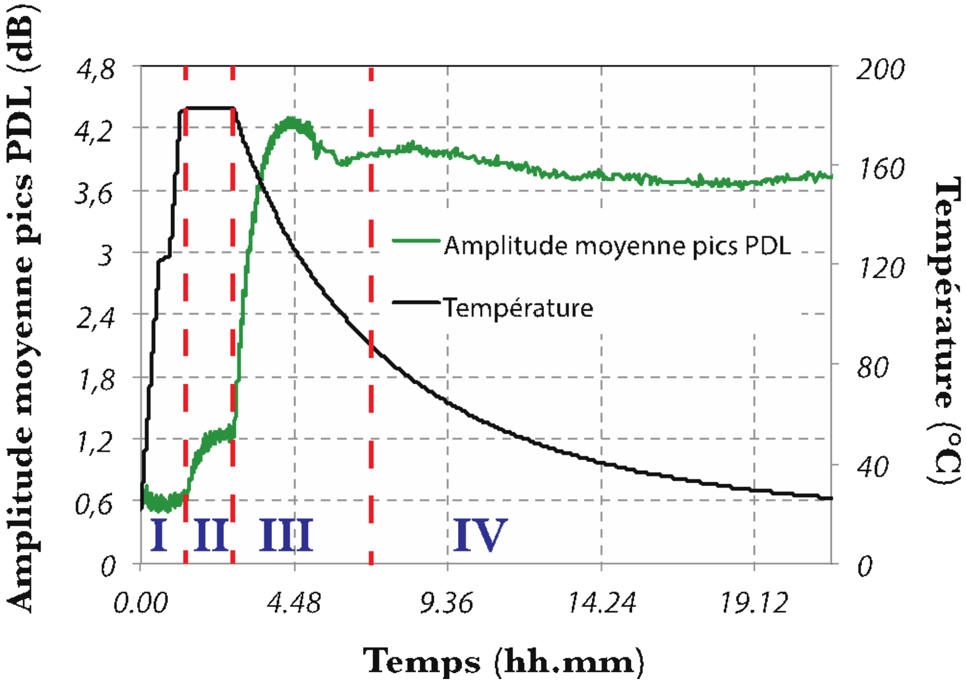

Figure 7 - Zone "I": the average peak amplitude of the PDL remains constant, it is the period before the "180°C plateau". Zone "II": a slight increase in amplitude is visible. This corresponds to the beginning of the "180°C plateau" phase during which the matrix begins to polymerise and to contract (chemical withdrawal due to crosslinking). This first increase stabilises at the end of the "180°C plateau" phase, which indicates that the resin is completely polymerised. Zone "III": the average peak amplitude of the PDL greatly increases. This corresponds to the beginning of the cooling phase. As the thermal expansion coefficients of the matrix and the carbon reinforcements are very different, this cooling generates thermal deformations which cause the formation of residual stresses within the composite. With regards to our Fibre Bragg sensor, this translates as an enlargement followed by its transmission peak being split as well as an increase in the peak amplitude of its associated PDL. Finally, we have Zone "IV": the peak amplitude of the PDL stabilises around an average value during the cooling phase whereas the thermal deformations are always continuous [2]

Figure 8 illustrates the fifth part (Commissioning) of figure 24. It presents two examples of deformation that a composite structure could suffer. Ten FBG sensors inserted in a single optical fibre have been embedded into this part to find the deformation value at different locations.

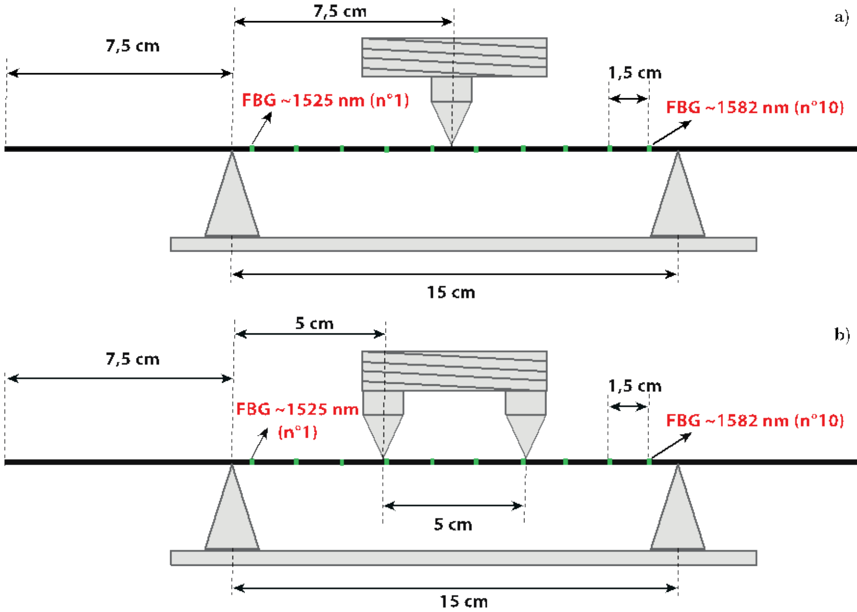

Figure 8 - Diagram of an (a) three point and (b) four point bending test with the position of the sensors embedded in the composite in relation to the support points [2]

Figure 9 validates the use of Bragg Grating sensors for measuring deformations within composite structures.

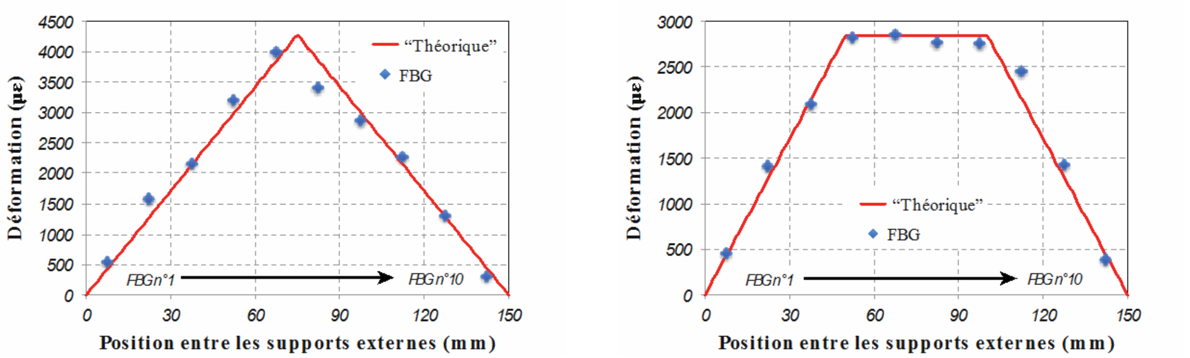

Figure 9 - On the left: Comparison between the deformation measured by the FBGs and simulated "three point" bending under a load of 633N. On the right: Comparison between the deformation measured by the FBGs and simulated "four point" bending under a load of 633N [2].

References

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