WHITE PAPER

Health-monitoring of composite materials using polymer optical fibers

SHUTE Sensing Solutions A/S, Oldenvej 1A, 3490 Kvistgaard, Denmark
Phone no.: +45 23 38 67 28, info@SHUTE.dk, www.SHUTE.dk

Introduction

As the use of composite materials have become a vital part of many industries, the demand for better diagnostics and monitoring of the material's state has grown. Many different sensor technologies have been used for these purposes, but none of them have had the sensitivity or versatility that polymer optical fiber sensors posses.

The easy to implement fibers can be put into many types of composite materials which uses different types of resin. Measurements such as strain and temperature are able to be measured at discrete points by the use of fiber Bragg gratings, which are inscribed into the fiber itself along several points.

The power of fiber bragg gratings in polymer optical fiber

As the fiber is implemented inside the composite material, the fiber Bragg grating(FBG) starts to react to the forces that are exerted upon the material itself. Intrinsic changes in strain and temperature are able to measured and can be used to test new materials and designs.

Putting multiple fiber sensors inside a material could be used to make an effective mapping of the strain or temperature profile across the entire surface of the material. This gives a better understanding of the different dynamics of the material and can even be used to verify the validity of complex structural simulations. In addition, polymer fibers are soft, small in size (diameter of $125\,\mu\mathrm{m}$), and do not create any defect by being embedding in the composite material.

Health-monitoring

The advantage of using SHUTE's sensors is that it can be used for monitoring of material health and damages in real time or used for single measurements. The SHUTE interrogator can be used to notify the operator when a change in health of the composite component is observed, even as it is being manufactured. This ensures the product being of the highest quality and also makes simultaneous measurements of multiple test and production setups a possibility.

Strain sensing in glass fiber composite

A material that sees use in many industries is glass-fiber reinforced epoxy and the application possibilities for plastic optical fiber based FBG are many. A few examples of the effectiveness and scope of the plastic optical fiber FBG technology can be seen in the following sections.

Construction of test application

Figure 1: Test sample being constructed

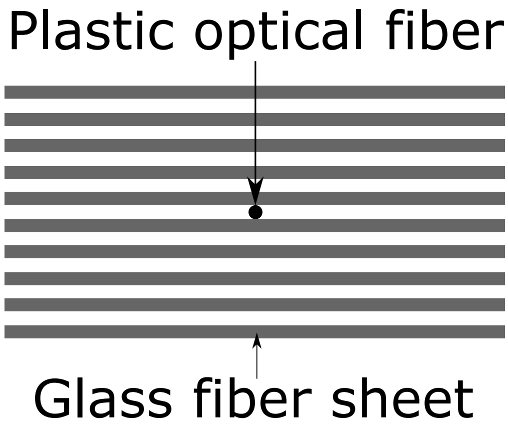

Figure 2: Illustration of the stack profile with an embedded fiber sensor.

An optical plastic fiber with a FBG was inserted into a 10 layer glass fiber composite material, made out of sheets of glass fiber and epoxy between the layers. The fiber was placed in the fifth layer and the signal from the FBG peak during the curing process of the epoxy, can be seen in figure 3.

The evolution of the peak can be directly translated to a measure of the temperature and strain changes that happens inside the composite material during the curing process, which may offer new insight on the effects of using different type of epoxy resin when constructing a composite part. In the specific case of the test specimen constructed in this paper, the epoxy resin makes an exothermic reaction and shifts the FBG peak wavelength.

When the resin begins to cool, the peak wavelength starts to return to the original value it had before it was implemented into the sample. However, as the resin hardens, an intrinsic stress is induced in the material. The difference in FBG peak wavelength before and after the curing may give an indication of how well the material hardened and also if there is too much intrinsic stress in the material.

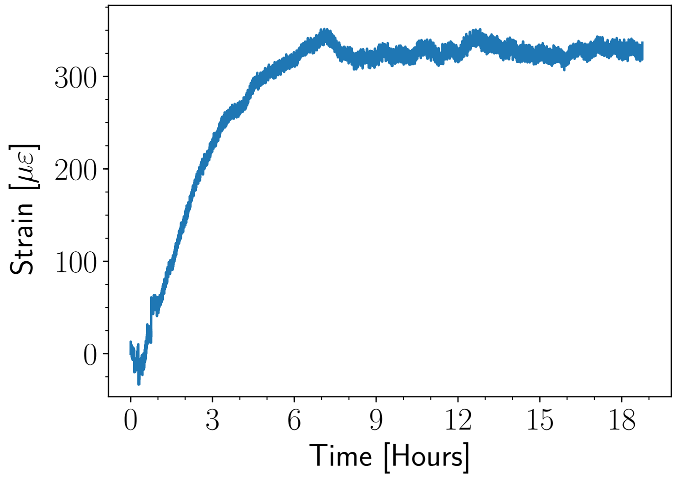

Figure 3: Evolution of the FBG wavelength shift, expressed as strain, during the curing process of the glass fiber composite.

Load-induced strain

The amount of strain a material experiences at a specific point can now be measured in real time, by placing heavy objects on the point where the FBG has been made, and track the movement of the FBG peak wavelength. The results of placing weights, as seen in figure 4, and applying additional pressure, can be seen in figure 5.

Figure 4: Multiple weights on top of the sensor

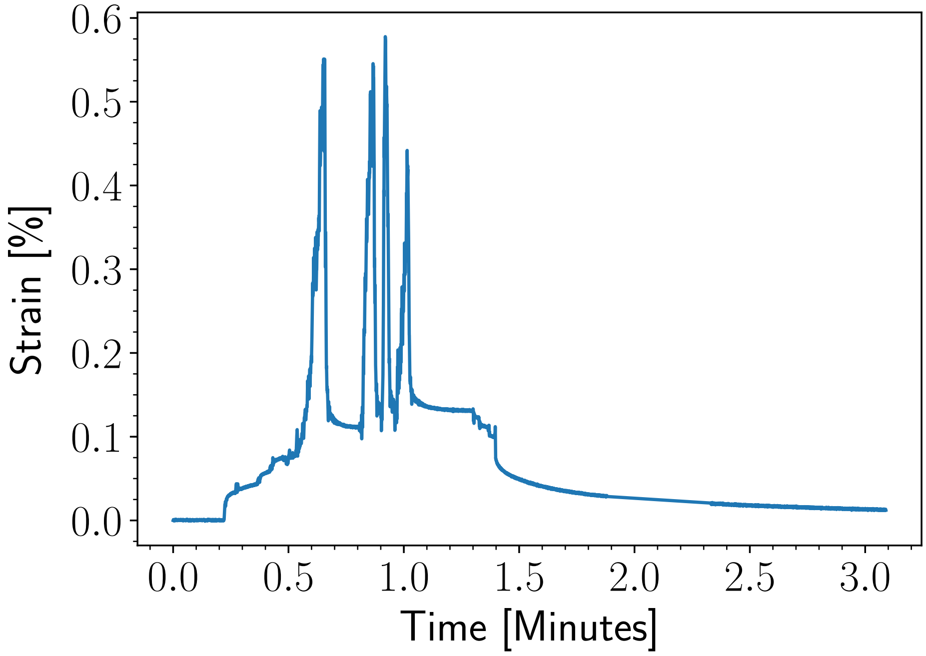

Figure 5: Strain measured in the plastic optical fiber while under heavy load from the weights seen in figure 4. The spikes are from manually pushing down on the weights.

In the start of the test, different weights where incrementally placed on top of the sensor, to reach a strain percentage of about 0.1. Thereafter, the weights were pushed down manually to reach a maximum of 0.55 % strain. After a series of pushes, the weights were taken of the sensor and the sensor went back to its non-pressured state.

This can be used to monitor the health of composite structures and ensure that the load on the composite is not too high. The sensors can be spread out over an entire surface, enabling real time monitoring of different structural points of interest.

Sensitive sensing

The sample was also tested in a 1 kN tensile stress machine, to demonstrate the high sensitivity of the FBG strain sensing. As seen in figure 6, the sample was held and stretched, in increments of 0.05 mm, linearly increasing the force used to stretch the sample, up to 1 kilo Newton.

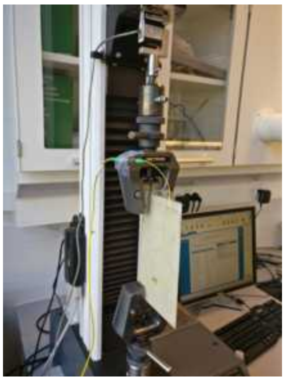

Figure 6: Setup for tensile stress test of measurement sample.

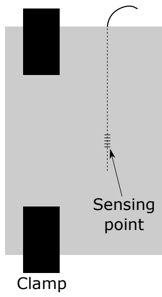

Figure 7: Illustration of the sensing point position relative to the clamps of the tensile strength test machine.

The result can be seen in figure 8, where a linear increase in strain is observed as the material is stretched. Even for small strain imposed in the material, the sensor is able to show the same linear behaviour of the tensile stress machine test.

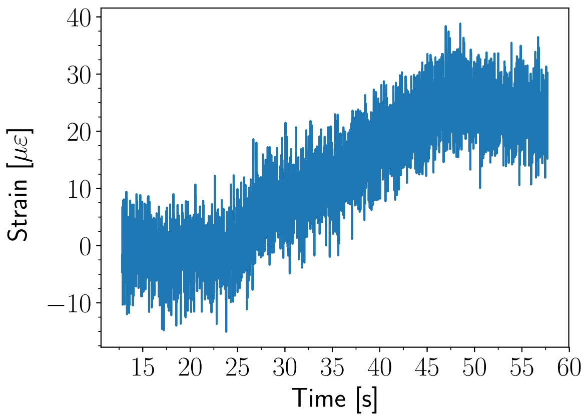

Figure 8: Strain profile of sensor during test in the tensile stress machine.

Even though the sensor is not in the center of the sample, where pulling of the sample has the highest effect, it can still measure the strain that is distributed through the sample.

Carbon composite sensing

As carbon composite has become a main staple in aerospace and high performance vehicles, increasing demands in quality control and health monitoring have pushed non-destructive testing to the center stage. Methods such as acoustic frequency analysis, x-ray tomography and infrared tomography have been used to estimate the severity of internal damages in the carbon composite. All of these methods require bulky systems to monitor changes in the structure of the composite and cannot easily be installed to measure the composite while it is in operation.

FBGs in plastic optical fiber offers the possibility of continuous sensing without having to remove the element or stop operation. FBG sensing offers strain and temperature measurements at points of interest in the carbon object itself, enabling the possibility of using it for validation of numerical models or health monitoring. The optical fiber gets embedded into the material and can have multiple points of measurement along one fiber. Different uses of this technology in carbon composite can be seen in the following sections.

Curing of test sample

An 8 layer 26 cm x 7.2 cm x 0.3 cm carbon composite plate was prepared with a plastic optical fiber, with 2 sensing points, embedded between the fourth and fifth layer. All layers were applied with no alternation in layer orientation.

Figure 9: Embedding of optical fiber in carbon plate.

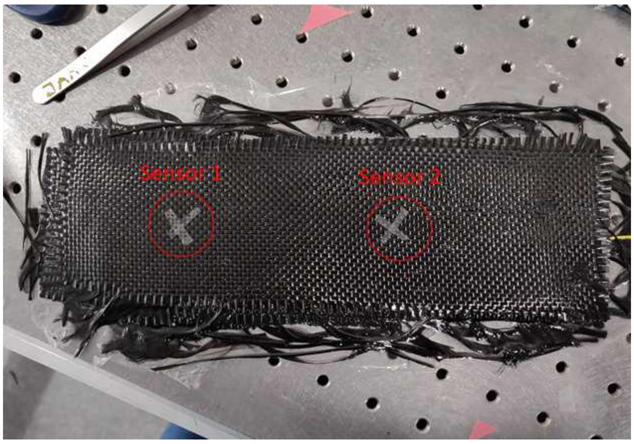

Figure 10: Marked positions of the embedded FBG sensors on the cured carbon plate.

The plate was left to cure for around 40 hours and a build up in intrinsic stress, corresponding to 600 micro strain, was observed. A dip in the intrinsic stress can be seen in the middle of the curing time and suggests that the optical fiber sensors can reveal important information about the dynamics of the curing process.

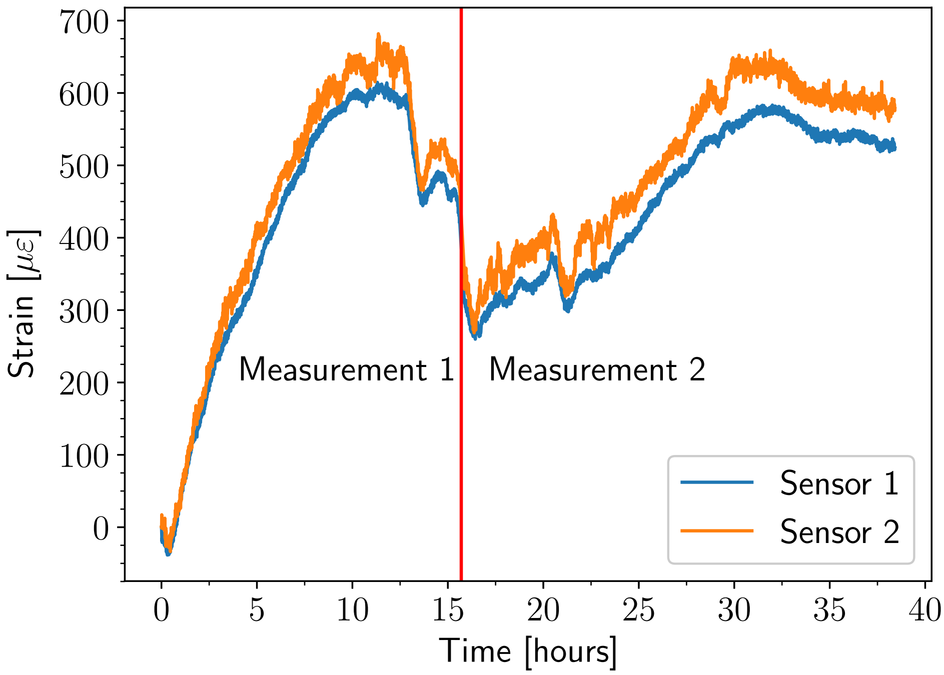

Figure 11: Strain recording from curing process of carbon plate with two different sensing points. The red line indicates the split between the first and second measurement, due to Measurement 1 being stopped before the plate was fully cured.

Bending of carbon plate

A simple bend test between two static supports can showcase the possibility of measuring different points of interest inside the carbon element itself. The constructed carbon plate was placed between to solid metal supports, as seen below in figure 12.

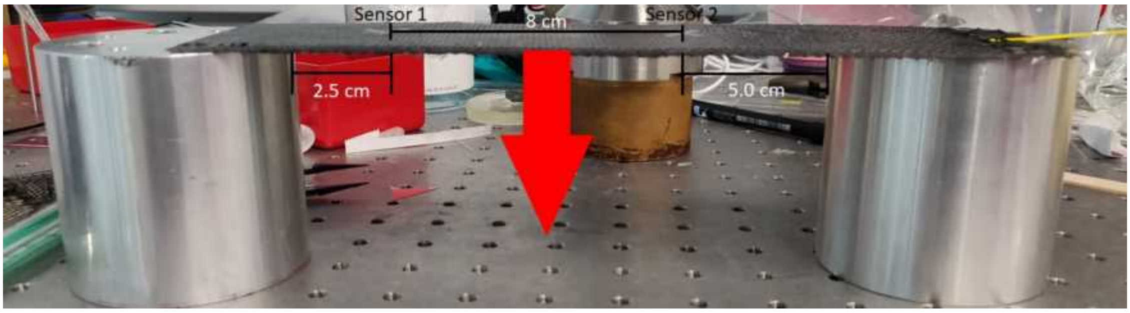

Figure 12: Setup for a bend test between two static points. Sensor 1 is placed 2.5 cm from the supporting block and Sensor 2 is placed 5 cm away from a supportive block. The position of the downwards bending force is illustrated by the red arrow on the figure.

The plate was bend manually at the position illustrated by the red arrow in figure 12 and the corresponding strain response from the two sensing points can be seen figure 13.

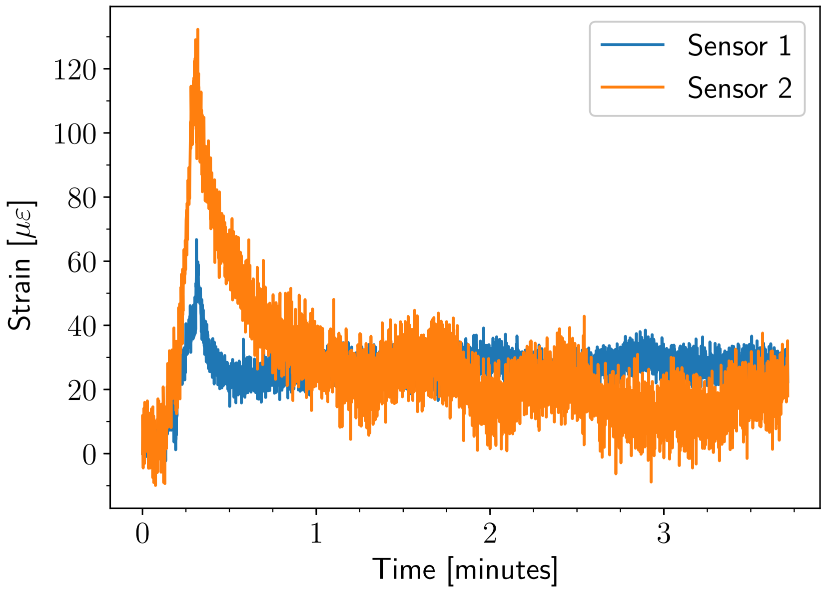

Figure 13: Strain response of FBG sensors during manual bend test.

The result of the manual bend test suggests a linear relationship between the strain experienced by the sensor and the distance between the sensor and supporting metal rod. Sensor 2 experiences double the strain of Sensor 1, due to Sensor 1 being 2.5 cm away from support while Sensor 2 is 5 cm away.

Another observation from the manual bend test is the strain measurement not returning to zero after the bending force has been removed from the plate. This can be an indication of internal damage inside the plate and is one of the main possible benefits of having polymer optical fiber sensors inside your carbon element. The amount of strain left in the plate can give a indication of how severe the internal damage is.

Impact test

The non-visible defects that can occur in a carbon based composite may not even come from extreme bending or deformation, but from objects, such as tools, being dropped on the sample during construction or maintenance.

A simple drop test was conducted, were a small 0.72 kg piece of metal with a blunt edge was dropped on the plate, approximately 4 cm from each sensing point. The metal object was dropped from a height of 1 meter above the plate, which equates to around 7 Joules of impact energy. The result of the drop test can be seen in figure 14.

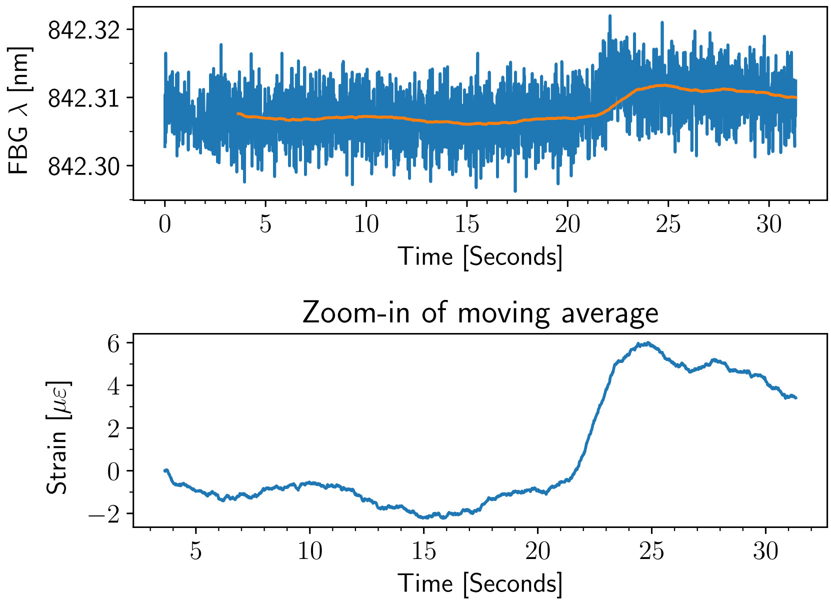

Figure 14: Wavelength response of FBG sensors during manual drop test. The yellow line in the top figure is the moving average of the data set, with a window size of 3.66 seconds. The bottom figure is a zoom-in of the moving average.

A sharp increase in the measured FBG wavelength can be observed around 22 seconds. This is the time of impact and the severity of the hit can be determined by the magnitude of the FBG wavelength shift. This depends on the distance between the impact zone and the sensing point itself, but the very sensitive plastic optical fiber FBG's may be able to detect internal damage in the composite, even if the defect is created away from the sensor.

Conclusion

There are many areas where plastic optical fiber sensing can be applied. Each specific use case can take advantage of the highly sensitive FBG's and their ability to measure strain and temperature inside a composite material. Quality control during curing and health monitoring are some of the major benefits to having plastic optical fiber FBG's embedded into the material.

Contact

For further information about the technology and how it applies to your potential use case, please contact :

CCO Kristian Rode

✉ kr@shute.dk
☎ +45 23 38 67 28
www.shute.dk