

**INTEGRATION OF MICROSTRUCTURED OPTICAL FIBRES INTO CARBON FIBRE REINFORCED PLASTIC MATERIALS – DETERMINATION OF THE INITIAL STRAIN STATE**

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**ABSTRACT**

The appearance of excessive residual strains during the manufacturing of composite structures is a major issue, as this can result in strength reduction, the creation of cracks or even delamination. The main origin of residual strain is thermal strain arising from the difference in thermal expansion coefficient between the main composite constituents, namely the matrix material and the reinforcement fibres. Fiber Bragg grating (FBGs) based optical fibre sensors are a powerful tool to perform internal measurements of strain and temperature. Fibre optic sensors appear to have interesting features to measure the build-up of residual strains during the cure cycle when embedded inside the composite part without disturbing the material structure [1]. Research in this field has so far been limited to the measurement of a wavelength shift attributed to longitudinal (in-plane) strain [2] and to temperature. An extra grating [3] or another type of sensor is used to compensate the influence of the temperature variations. All of those techniques require knowing the temperature at the exact location of the grating which is rather difficult in large carbon fibre reinforced plastic (CFRP) part and with high temperature variation. However, during the cure cycle the residual strain consists of thermal strain induced in all three directions. Fibre optic sensor based methods for determining the transverse (out-of-plane) strain have not been extensively investigated so far.

In this work, we describe how the use of a combination of two types of optical fibre sensors allows identifying the residual strains built up during the cure cycle. First we rely on FBGs in a highly birefringent microstructured optical fibre (MOF) specifically designed to be insensitive to temperature effects and to identify transverse strain components with a sensitivity ten times larger than that of conventional optical fibres [4]. The temperature insensitivity of the sensor stems from the very low

sensitivity of the phase modal birefringence of a MOF to temperature changes [5]. The transverse strain is encoded in the spectral distance  $\Delta\lambda$  between the two reflected resonance wavelengths of the FBG in such a fibre. Second, we use single mode fibres protected from the transverse effects to identify the longitudinal strain in combination with a system that corrects for the effects of temperature changes.

These two types of FBG-based sensors were embedded in a CFRP material. The composite laminate was produced by the vacuum bag autoclave technique. The lay-up was made of M10/T300 prepreg material (Hexcel) with a thickness of 6 mm. The optical fibre sensors were integrated at critical locations in the composite part in a specific fibre network to be able to monitor the residual strain creation at several locations. The composite structure was also instrumented with several thermocouples to monitor the temperature in the material at the FBG locations. The entire cure cycle was monitored by following the Bragg wavelength changes and the wavelength separation of the FBGs. Figure 1 presents the spectral distance versus the cure cycle for the MOF. It evidences a first drop of  $\Delta\lambda$  which is linked to the polymerization onset. Moreover it features a large decrease of the peak separation linked to the build-up of the residual strains during the consolidation phase. Eventually, using the sensor signal of the MOF we will be able to assess the transversal strain in the final composite piece while using the sensor signal of the second type of FBGs allows determining the longitudinal strains as well.

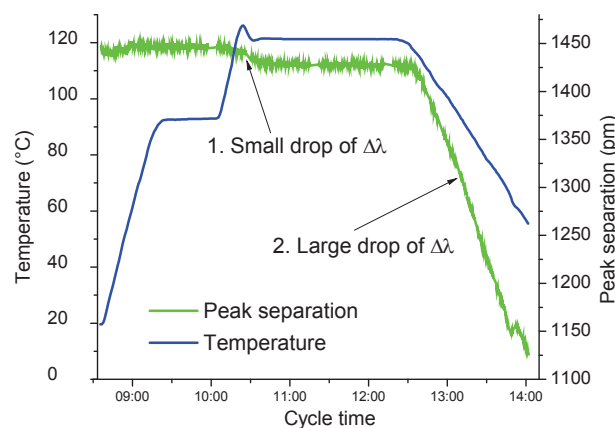


Figure 1: Variation of the temperature and of the peak separation ( $\Delta\lambda$ ) during the entire curing cycle.

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