SEMI-EXPERIMENTAL METHODS FOR STRESS ANALYSIS IN POLYMERIC MATERIALS WITH EMBEDDED OPTICAL FIBERS

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Abstract

Characterization of internal strains in polymers and composite materials is at the forefront of experimental mechanics. Experiments and analysis have demonstrated that embedded optical fiber Bragg grating (FBG) sensors are well suited for single and multiplexed strain measurements in composite materials and structures. They show an intrinsic self-referencing capability, have excellent resistance to corrosion and high temperatures, are immune to electromagnetic interference and are not susceptible to power fluctuations. Thus such sensors have attracted particular attention over the past few decades in the aerospace and automotive industries, manufacturing process monitoring, structural health monitoring, etc. While the advantages of embedded FBG, over other techniques, are very clear, a number of problems exists that need to be properly addressed and resolved. These relate to the fact that (i) strain measurements are made on the fibre itself while the interest is on the strains in the host material and (ii) the non-homogeneous strain field along the fibre which is difficult to construct with sufficient resolution.

Mechanically, the FBG sensor acts as an elastic inclusion in the host material. To obtain the strain and stress fields in the surrounding material a realistic micro-mechanics, physically based, model is needed. Such a model is not easy to establish given the essentially 3D nature of the problem and the local material morphology, especially in composite materials. When the sensor is embedded in a non-homogeneous strain field the interpretation of the sensor response, along its length is complicated. Typically the reflection spectrum becomes broader and several peaks appear. Such spectra modifications may be due to polarisation induced lateral strains and/or non-homogeneous strains along the fibre axis. In addition a spectrum obtained by standard procedures is an integral form of response and details regarding the strain distribution are not apparent. This form of the signal complicates the identification of the actual distribution on the fibre, especially in cases of high strain gradients. Even if various techniques, like the T-matrix formalism, are available to predict spectra modifications, from a given strain distribution, the inverse problem, i.e. the determination of the applied strain from a measured spectral response, is a tedious task and require assumptions on the strain profile and several iterations. In cases where non-homogeneous strains prevail, technique based on FBG spectra synthesis should be used. Such methods can provide distributed strains over several millimeters thus, capturing the essential attributes of the actual strains due to damage, delamination, residual strains, etc. However they are not always suited for measurements under dynamic loads.

One of the major advantages of the FBG sensors is that they can be multiplexed. It means that several short FBGs, each one with slightly different Bragg wavelength, can be inscribed on the same fiber and be interrogated simultaneously. Thus, strain data can be obtained in several points of the structure by monitoring the wavelength changes of each FBG sensor. Such quasi-distributed strains can be very useful in damage characterization and structural monitoring. Progress in high rate interrogation systems for short Bragg gratings permits the use of FBG sensors in dynamics experiments. In this presentation, the merits and limitations of FBG sensors for internal strains are mentioned and experimental results are presented in various configurations. These include: (a) residual strains due to curing, (b) strains through the thickness of a composite, (c) strains due to delamination, (d) modal and damage analysis due to low energy impact, etc. Such strain data are confronted with analytical and numerical models. The present studies demonstrate that internal strain measurements using embedded FBG sensors, accompanied by appropriate modeling, can provide important data for the characterization of deformation and fracture of polymeric materials. Such results can also offer sound basis for the development of realistic structural health monitoring methods.

References

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