DELAMINATION PROPAGATION MEASUREMENT IN AS4/PPS USING LONG GAUGE-LENGTH FBG SENSORS

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ABSTRACT

With the increasing use of polymer composite laminates as structural materials, we need to expand our understanding and characterization of their damage mechanisms. In particular, it is important to consider how a delamination in a laminated composite changes the surrounding internal strain state. In this work, knowledge of the distributed strains near a delamination front is obtained through the use of fibre Bragg grating (FBG) sensors, which are interrogated using an OLCR-based technique that measures the phase of the light reflected at incremental positions in the FBG [1]. This method allows us to precisely locate the delamination crack tip position with respect to an FBG, even under conditions where there is an initial residual strain state that has induced birefringence in the sensor. Since this technique allows the determination of the position, length and growth direction of a delamination crack propagating parallel to the FBG, it represents an advance beyond purely spectral measurements, which may be difficult to interpret and do not uniquely represent a given strain state.

To introduce the advantage of this method, consider in a qualitative manner, how an FBG sensor responds to the strains produced by a mode I delamination crack propagation in a double cantilever beam specimen (Figure 1). If the period and index of refraction are changed by applying strains to the FBG, then the wavelength of the reflected light will shift according to the equations developed by Sirkis [2], assuming isothermal loading:

$$\frac{\Delta \lambda_{bx}}{\lambda_B} = \varepsilon_z - \frac{n_0^2}{2} \left[p_{11} \varepsilon_x + p_{12} (\varepsilon_z + \varepsilon_y)\right]$$  

$$\frac{\Delta \lambda_{by}}{\lambda_B} = \varepsilon_z - \frac{n_0^2}{2} \left[p_{11} \varepsilon_y + p_{12} (\varepsilon_z + \varepsilon_x)\right]$$

where $\Delta \lambda_{bx}$ and $\Delta \lambda_{by}$ are the shifts in Bragg wavelength for the two polarization axes in the fibre, $\varepsilon_i$ ($i = x, y, z$) are the principal strain components in the fibre core, and $p_{11}$ and $p_{12}$ are the strain-optic Pockel’s constants.

Consider an FBG sensor embedded parallel to a bridged delamination crack, and thus subject to a distributed strain field $\varepsilon(z)$ along the sensor length (Figure 2a). The wavelengths reflected by the FBG, $\lambda_{bx}(z)$ and $\lambda_{by}(z)$,
also become a function of position (z). As a first approximation, the expected spectral response of the FBG can be obtained by neglecting the influence of the transverse strains (for the simplicity of the illustration), so that equations 2a and b both become

$$\frac{\Delta \lambda_b (z)}{\lambda_B} = (1 - p_e) \epsilon_z (z)$$  \hspace{1cm} (2)

where $p_e$ is an effective photoelastic constant. The resulting spectrum should have a large peak at a high wavelength, corresponding to the relatively constant strain in the fibre behind the crack tip. It should also have a large peak at a low wavelength corresponding to the undisturbed portion of the FBG which will reflect the original Bragg wavelength. Finally, there should be a distribution of wavelengths between the two peaks corresponding to the strain evolution around the crack tip. This type of spectrum is illustrated in Figure 2b and was also observed by Takeda et al. [3]. Although this spectral evolution is quite clear, it lacks spatial correlation. A crack could arrive from either end of the FBG and produce the same spectral form, indicating one way in which the spectral form is not a unique indication of strain state. Another complication in the interpretation of wavelength spectra is encountered when a composite contains a residual strain field that creates unequal transverse strains in the embedded FBG, making equation 2 invalid. Under these conditions the spectral response will be dependent on the polarization state of the interrogating light, and therefore, wavelength spectral form, position and amplitude may vary from one measurement to the next, if the polarization state is not maintained.

![Figure 3 - Measurements of wavelength shifts due to the progression of a delamination crack below an FBG](image)

In this research we use the OLCR-based approach to measure the FBG response to different delamination lengths (Figure 3). In this way no assumptions need to be made about the distribution or form of the reflected wavelengths and it possible to control the polarization of the light entering the FBG, so that its response is measured separately for each of the polarization axes of the fibre ($\lambda_{bx}$ and $\lambda_{by}$). We observe that transverse residual strains are unequal in the FBG, causing a birefringence ($\lambda_{bx} \neq \lambda_{by}$); however, this difference disappears once the crack front passes below the FBG. Although it is possible to see some effect of the transverse strain field in the FBG response, it is clear that the most significant contribution is made by the longitudinal strains. This is illustrated by comparing the shape of the strain curve in Figure 2a, and the shapes of the measured wavelength curves. In order to provide a complete interpretation of the distributed wavelength measurements, they are coupled with appropriate numerical models to allow for a quantitative description of the strain field around the delamination.

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REFERENCES

