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INVESTIGATION OF STRUCTURAL PROPERTIES OF CARBON-EPOXY COMPOSITES USING EMBEDDED FIBER-OPTIC BRAGG GRATINGS

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Introduction

Real time monitoring of the mechanical integrity and stresses on key aerospace composite structures like aircraft wings, walls of pressure vessels and fuel tanks or any other structurally extended components and panels as in space telescopes is very important to NASA. Future military and commercial aircraft as well as NASA space systems such as Space Based Radar and International Space Station will incorporate a monitoring system to sense any degradation to the structure. In the extreme flight conditions of an aerospace vehicle it might be desirable to measure the strain every ten centimeters and thus fully map out the strain field of a composite component. A series of missions and vehicle health management requirements call for these measurements. At the moment thousands of people support a few vehicle launches per year. This number can be significantly reduced by implementing intelligent vehicles with integral nervous systems (smart structures). This would require maintenance to be performed only as needed. Military and commercial aircrafts have an equally compelling case. Annual maintenance costs are currently reaching astronomical heights. Monitoring techniques are therefore required that allow for maintenance to be performed only when needed. This would allow improved safety by insuring that necessary tasks are performed while reducing costs by eliminating procedures that are costly and not needed.

The advantages fiber optical sensors have over conventional electro-mechanical systems like strain gauges have been widely extolled in the research literature. These advantages include their small size, low weight, immunity to electrical resistance, corrosion resistance, compatibility with composite materials and process conditions, and multiplexing capabilities. One fiber optic device which is suitable for distributed sensing is the fiber Bragg grating (FBG). This is a periodic perturbation in the refractive index of the fiber core. When a broadband light is coupled into the optical fiber sensor, a reflection peak will be obtained centered around a wavelength called Bragg-wavelength. The Bragg-wavelength depends on the refractive index and the period of the grating, which both change due to mechanical and thermal strain applied to the sensor. The shift in the Bragg-wavelength is directly proportional to the strain.

Researchers at NASA MSFC are currently developing techniques for using FBGs for monitoring the integrity of advanced structural materials expected to become the mainstay of the current and future generation space structures. Since carbon-epoxy composites are the materials of choice for the current space structures, the initial study is concentrated on this type of composite. The goals of this activity are to use embedded FBG sensors for measuring strain and temperature of composite structures, and to investigate the effects of various parameters such as composite fiber orientation with respect to the optical sensor, unidirectional fiber composite, fabrication process etc., on the optical performance of the sensor.

This paper describes an experiment to demonstrate the use of an embedded FBG for measuring strain in a composite material. The performance of the fiber optic sensor is determined by direct comparison with results from more conventional instrumentation.

Optical Fiber Selection and Fabrication of Bragg Gratings

Two fiber buffer materials (Acrylic and Polyimide) were selected for the study, which met the fabrication process, temperature, and strain requirements of the proposed composite. High reflectivity Bragg gratings were produced into the core of the single mode, Germanium doped optical fibers using the phase mask method (Hill et al. 1993). The optical fibers were hydrogen loaded (Lemaire et al.) under high pressure to increase photosensitivity prior to writing the grating. A continuous wave argon ion laser operating at 244 nm (second harmonic of the blue line) was used as the source for writing the gratings at Bragg wavelengths around 1300 nm and a bandwidth of around 0.5 nm. Real-time monitoring of grating growth was carried out during the writing process by illuminating the grating with broadband source (a laser diode) covering the grating reflection spectrum. Transmission and reflection spectra were measured with the aid of a monochromator and a recorder.

Embedded Optical Fibers

Carbon /epoxy composite panels, with embedded optical fiber sensors were fabricated using the NASA-MSFC composite fabrication facilities. The carbon/epoxy prepreg used for the panel fabrication was provided by NASA. The fabrication technique focused on the hand lay-up and autoclave cure. Three prominent lay-up orientations (0, 90, and 45 degree) of the fibers (uni-tape and fabric) in the composite lay-up were selected for the study. The optical fiber was arranged to lie parallel, at 45^{o} angle, and perpendicular to the carbon fibers.

Test Set—Up

Shown in Figure 1 is a schematic of the set-up used for performing physical tests on the composite panels fabricated with the embedded Bragg gratings [2,3,5]. The composite was tested under axial tension. It was gripped on either end in a special hydraulic wedge grips. Approximately one inch of the composite was gripped by each of the two wedge grips. A compact tunable diode laser was used to couple light into the optical fiber. The transmission spectrum of the grating was recorded with the aid of a detector and a lock-in amplifier. The tensile loading was increased continuously from zero to maximum at any desired rate. Shift in the Bragg wavelength was obtained from the transmission spectrum. The software developed in house converts this shift into longitudinal strain and plots the load strain data. Longitudinal as well as transverse strains were measured simultaneously and used to determine Poisson's ratio for the composites.

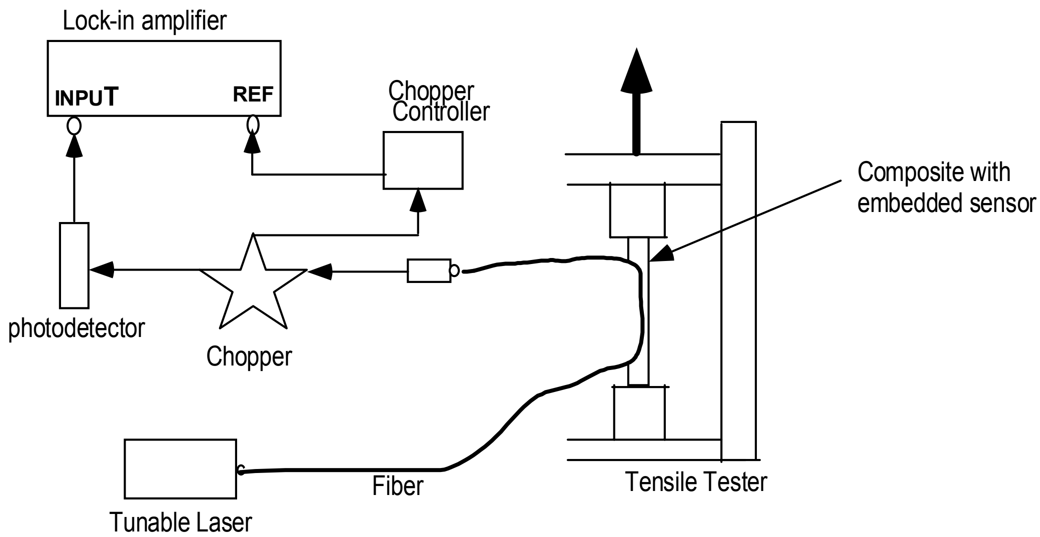

Figure 2: The Experimental Set-Up

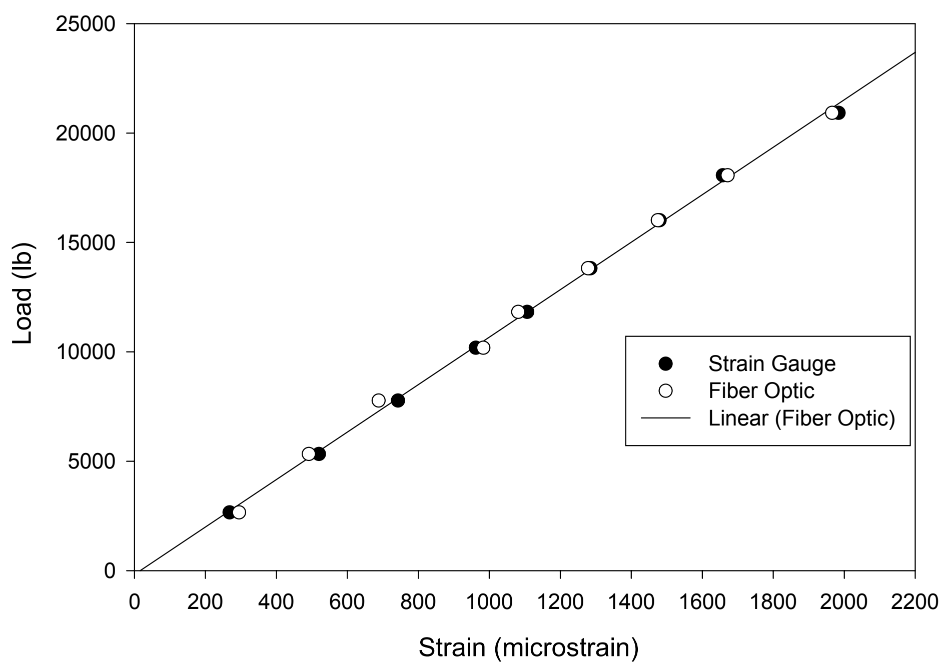

Figure 2. Load versus Strain

Results and Discussions

A plot of load versus strain is shown in Figure 2. The actual strain values were obtained from the fiber optic strain by dividing fiber optic strain measurements by 0.78 as discussed in the literature. Excellent agreement between the strain gauge measured strain and that of the fiber optic sensor is evident. A linear regression of the fiber optic data was performed and the equation is displayed in the figure.

More sets of data were taken and the plots described above were done for each set. Plots of only one data set are shown for convenience. Results show a good repeatability for the experiment.

Concluding Remarks

Optical fibers with Bragg sensors have been embedded into carbon-epoxy composite to measure the tensile strain in the composite material. Excellent agreement between strain measurements from a more conventional instrumentation and the Bragg sensors has been verified. The experimental results of this preliminary study indicate that fiber optic Bragg grating sensors, integrated with composites, have potential applications for monitoring the structural integrity of composite structures.

Acknowledgements

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