Fatigue Performance Comparison between OFDR-based Distributed Fiber Optic Sensing and Strain Gages

Contents

Introduction

Resistive strain gage cycle life decreases dramatically as strains reach values of 2000-4000 µstrain[1]. This results in early gage failure and the inability to accurately assess structural performance from load and deflection controlled tests. The superior characteristics of fiber optic strain sensors pave the way for overcoming this limitation and support their use for fatigue testing and other high-strain cyclic monitoring. Luna's Optical Frequency Domain Reflectometry (OFDR)-based distributed fiber optic sensing technique provides the ability to make numerous strain measurements with millimeter spatial resolution along the length of an optical fiber. OFDR is the underlying technique used in our OBR, ODiSI, and DSS product lines for distributed sensing. This Engineering Note presents comparative measurements between foil gages and fiber optic sensors in two experimental configurations.

Test Setup

Two tests were designed to compare fiber optic sensors and foil gages. In the first, fiberglass coupons were clamped in a cantilever configuration and deflected cyclically. In the second, fiberglass coupons were held in a custom-built four-point bending test fixture affixed to an MTS load frame and loaded cyclically. In both cases, a fully reversed load was applied.

Cantilever Configuration

A commercially available, low bend loss, polyimide coated optical fiber was bonded to the front side of a fiberglass coupon, along its length. A foil strain gage was located immediately beside the fiber sensor at the root of the cantilever. When installing foil gages, care was taken during adhesive and solder application to minimize stress concentrations at both the bond line and solder connection. Strain relief of lead wires was implemented either using intermediate terminal strips or taping down lead wires close to the foil gage. A motor connected to the cantilever tip cyclically deflected the tip, resulting in root strain of approximately ±4000με. Foil gage and fiber sensor strain measurements were taken at zero, maximum, and minimum strain after every 50 continuous cycles.

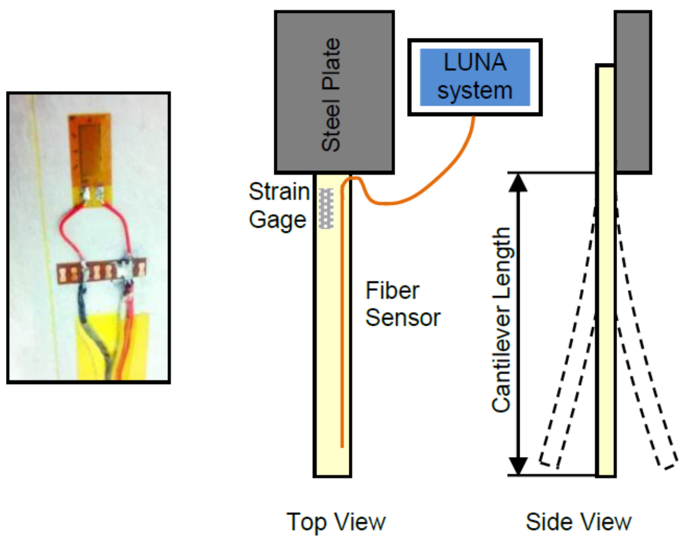

Figure 1: Schematic of fatigue test setup for experiment one.

Four-Point Bend Configuration

A custom-built four-point bending test fixture affixed to an MTS load frame (Figure 2A). The four pairs of rollers (Figure 2B) act as simple supports for each fiberglass coupon that was inserted.

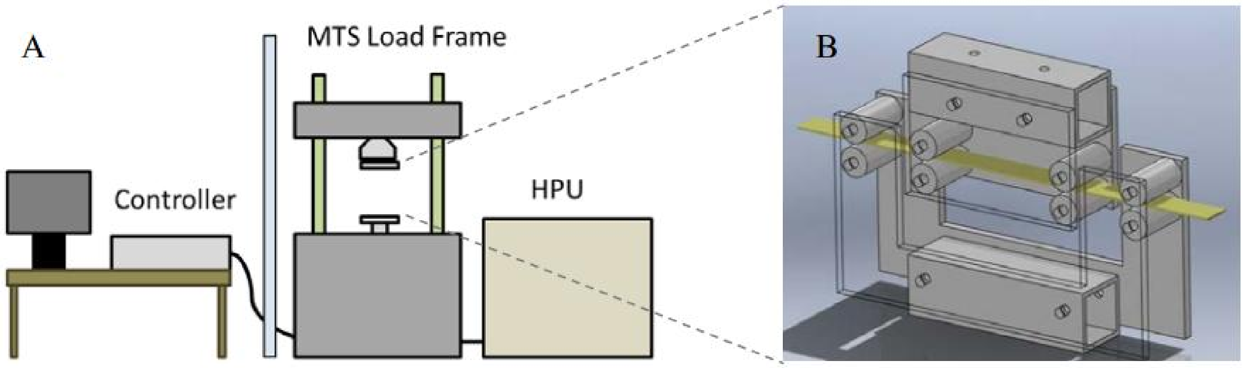

Figure 2: A. MTS load frame, controller, and HPU. B. Custom four-point-bend test fixture.

A foil strain gage was bonded in the middle of the top side of each coupon. An optical fiber was then bonded beside the foil gage, with two fiber runs on the top and two fiber runs on the bottom of the coupon (Figure 3). Each fiberglass coupon was cyclically loaded for 1000 cycles at a strain of approximately ±4000με in the middle section of the coupon.

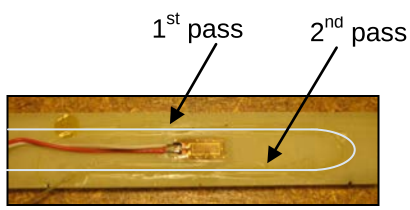

Figure 3: Fiberglass coupon instrumented with a foil strain gage and two passes of fiber optic sensor.

Table 1 below outlines the parameters of the various materials used in these tests.

Coupons			
Material		Fiberglass	
Dimensions		1/16" thick, 3/4" wide	
		Cantilever	**Four-Point Bend**
Length		3.7"	12"
Tip Deflection		0.65"	-
Strain Range		± 4000 µStrain	± 4000 µStrain
Number Tested		4	5
Adhesive			
Type		M-Bond 200 (Vishay)	
Strain Sensors			
OFDR	Fiber type	Polyimide-coated low bend loss fiber	
	Gage length	0.5 cm	
	Strain coefficient[2]	1 GHz = 6.58 µStrain	
Strain Gage	Type	Quarter-bridge EA-series	
	Gage factor	2.13	
	Resistance	350 Ω	
	Gage length	1/4"	

Table 1: Material parameters for test setup

Results

Cantilever Configuration

The percent deviation from the expected strain value as a function of number of cycles was recorded for both fiber optic sensors and foil strain gages in the cantilever test configuration. As can be seen in Figure 4, the foil gage deviates from the expected strain value with increasing number of cycles, whereas the fiber measurement stays constant. Deviation values are reported as a percentage of the strain range (here 7550με).

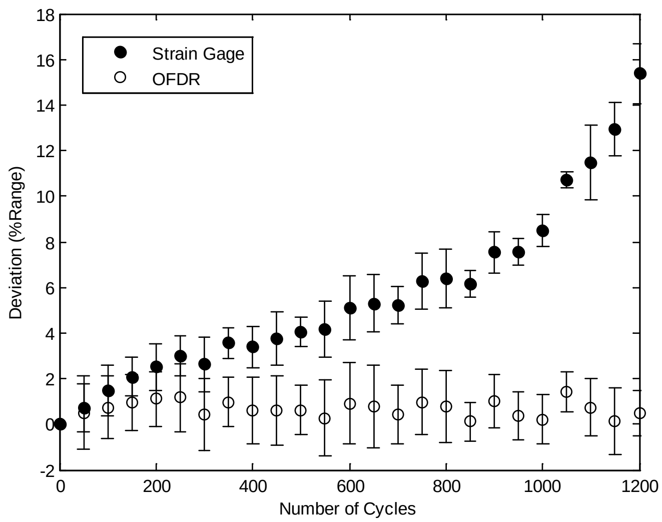

Figure 4: Percentage deviation of strain measurements with number of cycles for a single coupon.

Four-Point Bend Configuration

In the four-point bend test, while the optical fiber measurement remained constant through the end of cycling, the foil strain gages immediately begin deviating from initial measurements (Figure 5). Two of the five strain gages used exhibited catastrophic failure after a few hundred cycles due to rupture of the strain gauge filament.

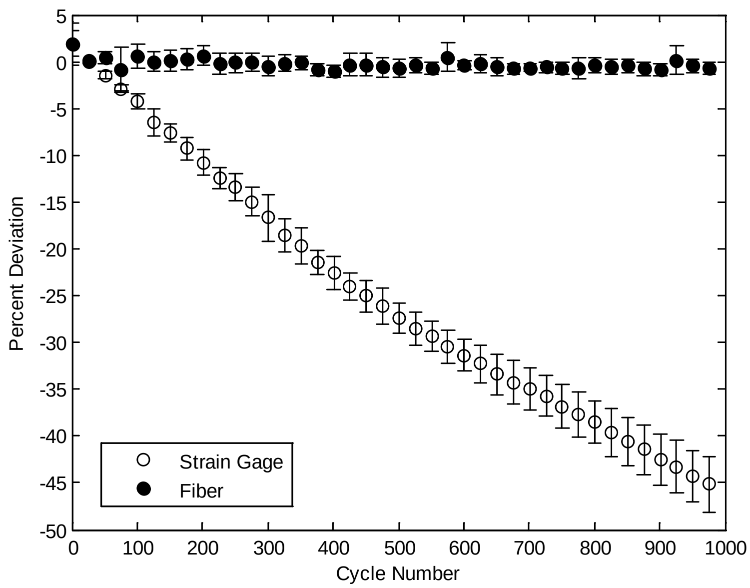

Figure 5: Percentage deviation of minimum strain for each cycle, from initial minimum strain.

Fatigue testing was subsequently carried out for 27,000 cycles with the fiber showing no deviation from its initial measurements, as shown in Figure 6. The test fixture was adjusted at 100 cycles and after 1000 cycles, causing small discontinuities in the minimum strain applied to the coupon.

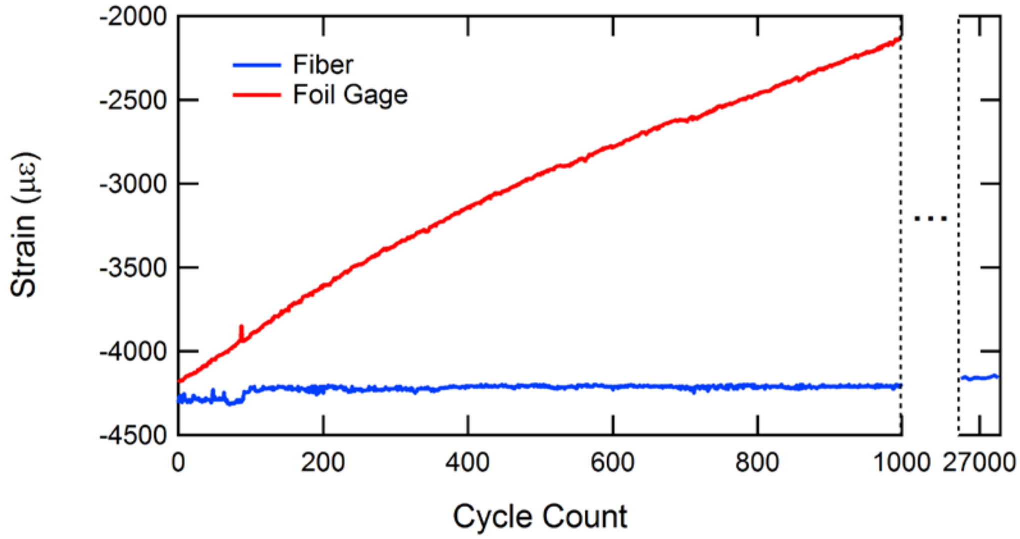

Figure 6: Strain as a function of number of cycles. The foil gage suffers from severe drift where the fiber sensor continues to measure accurately up to over 27,000 cycles.

Conclusion

High resolution distributed fiber optic strain sensing is used to investigate the performance of surface-bonded low bend loss polyimide coated optical fiber sensors during high-strain cyclic tests. The sensors were applied to fiberglass coupons subjected to a +/-4000 μstrain cyclic load. Two test setups were established, one with the coupon in a cantilever configuration and the other in a four-point bend configuration. In both, all foil strain gages demonstrated cumulative zero-shift in strain early in the test cycle, which increased in magnitude throughout the test. On the other hand, all fiber optic sensors survived the fatigue tests and demonstrated consistency in strain measurements through the end of the test. The susceptibility of foil strain gages to fatigue damage when strained cyclically at high amplitudes limits their suitability for high-cycle monitoring. Subsequently, the superior fatigue characteristics of fiber optic strain sensors pave the way for overcoming this limitation and support their use for fatigue testing and other high-strain cyclic monitoring.

1 Vishay Datasheet available at http://www.vishaypg.com/docs/11058/tn5081.pdf

2 Strain measurements are calculated from the spectral shift of scattered laser light. The default conversion rate used here is from *A. Othonos and K. Kalli, Fiber Bragg Gratings (Artech House, Boston, 1999*

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