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Reliability of Smart Composite Materials

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Reliability of Smart Composite Materials

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ABSTRACT

A smart composite material is a structure which contains a built in sensing device, used to monitor the current state and serviceability of a structure over its entire service life. One such type of sensing device is a fiber optic strain sensor. The small size of these strain sensors and their leads means that they can be embedded within a composite material without degrading its mechanical properties. As well, if the sensor is embedded in the cross section of an FRP composite product such as rebar, then the sensor will be protected from rough handling during fabrication and construction phases. Externally bonded gages are inherently more susceptible to damage or failure. As an added benefit, embedded fiber optic strain gages can be used as a quality assurance tool during the manufacturing process for the FRP composites, in measuring such parameters as degree of cure for the resin matrix system. As compared to conventional types of foil strain gages, fiber optic strain sensors are light weight, resistant to corrosion and electromagnetic interference, and have excellent sensitivity.

The overall goal of the current research is the production of both fiberglass and carbon fiber composite tendons which contain embedded fiber optic strain sensors. These 9mm diameter composite tendons are a good study model for fiber reinforced plastic (FRP) products such as rebar, prestressing tendons, rock bolts, and ground anchorages. The advantages of these FRP products as compared to their steel counterparts include excellent corrosion resistance and a high strength to weight ratio. For example, FRP rebar is resistant to harsh chemical environments including the detrimental chloride attack seen in steel rebar used in marine applications or in areas exposed to deicing salts. The smart composite reinforcements are produced with the pultrusion process, as this is an extremely cost effective manufacturing process for composites, and because pultruded products typically contain a high degree of axial reinforcement, ideal for prestessing tendons and rebar.

Two types of optical fiber strain sensors were used to produce the smart composite reinforcements: Fabry Perot and Bragg Grating sensors. The performance of the smart reinforcements is currently being evaluated through an extensive mechanical testing program which simulate the anticipated in service conditions. These tests are designed to gain information with respect to the long term reliability of the fiber optic sensors, as it is expected that typical applications may have expected life spans of 50-100 years. The strain readings from the embedded optical sensors are compared to that from externally affixed extensometers and foil gages which represent the traditional methods of strain measurement. The performance of the smart composite tendons were evaluated under the following test regimen:

1. Tensile ramp and sinusoidal waveform proof loadings.
2. Proof loadings at temperature extremes ranging from -40 to +60°C.
3. Tension-Tension fatigue testing.
4. Short term creep.
5. Long term creep with harsh environmental exposure.

The results of this testing program will be presented and discussed. Generally, the embedded optical sensors were in good agreement with the extensometer and strain gage devices.

A new phase of the research will begin in the spring of 1999, when the smart composite tendons will be evaluated in field applications. One such project involves the placement of the tendons in concrete seawalls, as part of a restoration project at Halls Harbour, N.S. Other applications for the technology are also being explored.

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Research Goals:

- *Pultrusion* of GFRP and CFRP composite reinforcements with embedded fiber optic strain sensors.
- *Evaluation* of sensors' performance under tensile loading conditions

Why Composite Materials?

- Corrosion Resistance
- High Strength to Weight Ratio
- Non-Conducting

Civil Engineering/Concrete Applications:

- Prestressing Tendons
- Rebar
- Column Wraps for Rehabilitation

Properties of GFRP vs. Steel Rebar

	GFRP	Steel
Ultimate Tensile Strength	160,000 psi	70,000 psi
Yield Strength	100,000 psi	40,000 psi
Modulus of Elasticity	7 x 10E6 psi	30 x 10^6 psi
Strain at Failure	2-3%	
Weight	0.09 lbs/ft	0.376 lbs/ft
Cost	2x	1

Typical Applications Have Included:

Location	Exposure
Parking Garages	Deicing Salt
Bridge Decks	Deicing Salt
Marine Structures	Saltwater
Reservoirs for Papermills and Chemical Plants	Acidic and Caustic Solutions

Advantages of Fiber Optic Sensors

- Light weight
- Corrosion resistant
- Excellent Sensitivity
- No EMI losses
- No Spark Hazard
- Reduced Cabling
- "Easily Embedded"

Why Smart Composites?

Monitor Structure During:

- Fabrication
- Installation
- In-Service

Examples:

- Degree of Cure
- Damage Detection
- Service or Process Induced Strains

Why Smart Composites? (Cont'd)

Because Composites are "new kid on the block"

The Internal Sensing Component will:

Give designers more confidence in composites

Greater use of composites in traditional industries:
Civil, Transportation, Marine

Individual Components of Smart Composite Material

- Reinforcing fiber for strength and stiffness
- Resin matrix to bind and protect fibers from harsh environments
- Optical Sensors to measure strain

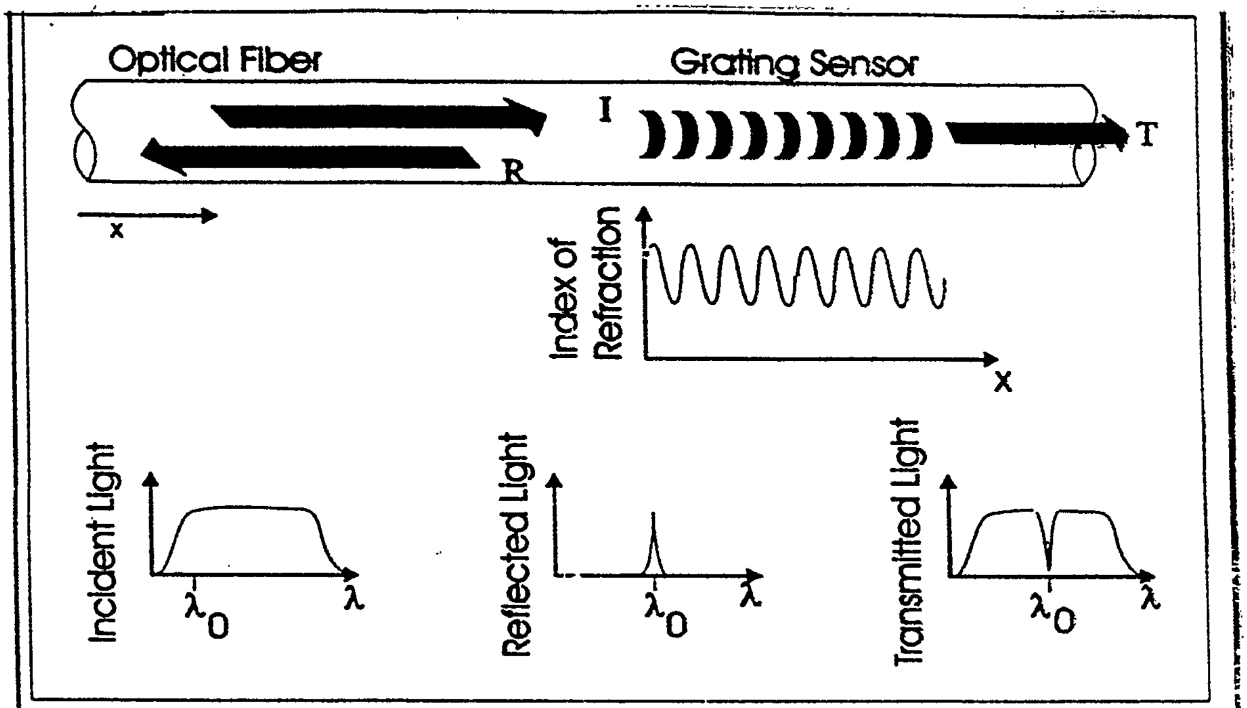
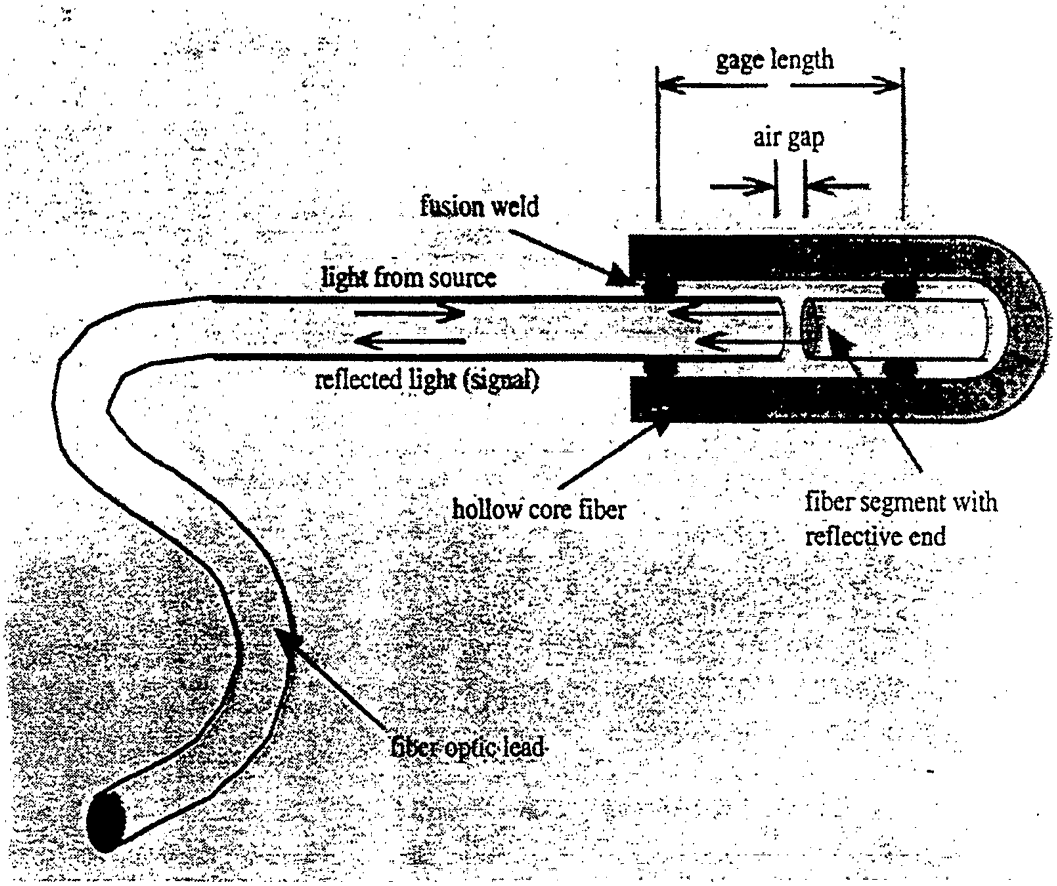


Figure 2: Bragg Grating Description



Advantages of Pultrusion

- single machine operator
- continuous 24 hour operation
- low wastage or scrap
- may use inexpensive raw material formats

Limitations of Pultrusion

- Commercially limited to parts with constant cross section

Production Issues for Smart Composites

Optical fiber should not compromise structural integrity of the host composite material.

Composite processing parameters should not compromise the performance of the optical fiber.

Ideally, optical fiber should not affect the producibility of the composite.

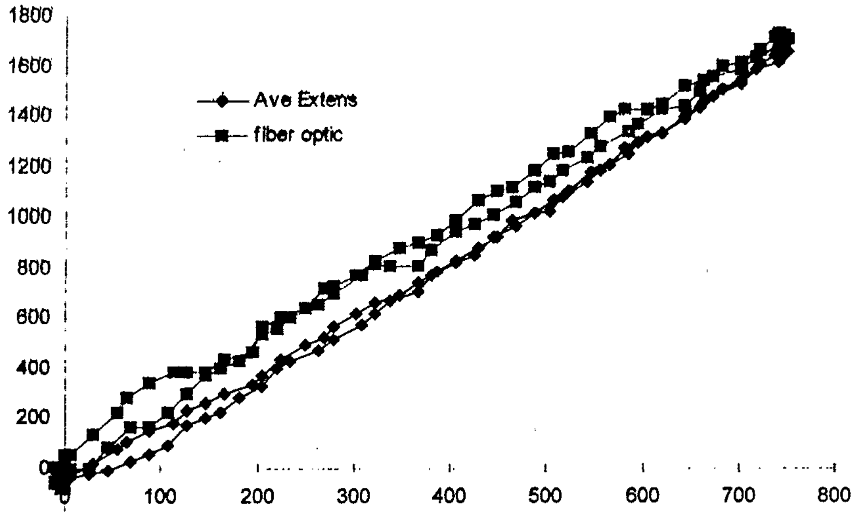
Durability and Performance Test Program

- Tensile Ramp & Cyclic Loading Ambient
- Performance at Temperature (-40 to +60)
- Tension-Tension Fatigue Loading
- Short Term Creep (300 Hours)

Durability and Performance
(cont'd)

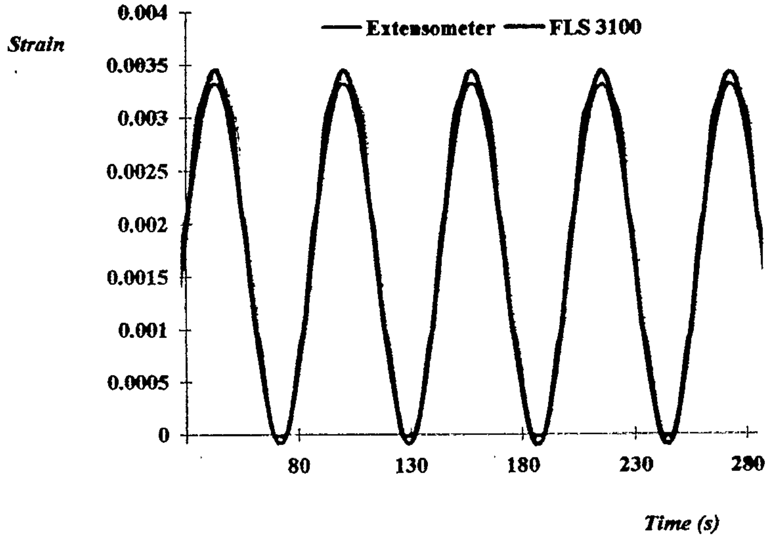
- Long Term Creep (2000 hrs.)
- Environmental Exposure
- Long Term Creep and Environmental
- Destructive Tests (max. capacity sensor)

Output From Bragg Grating Sensor Embedded in GFRP Rod

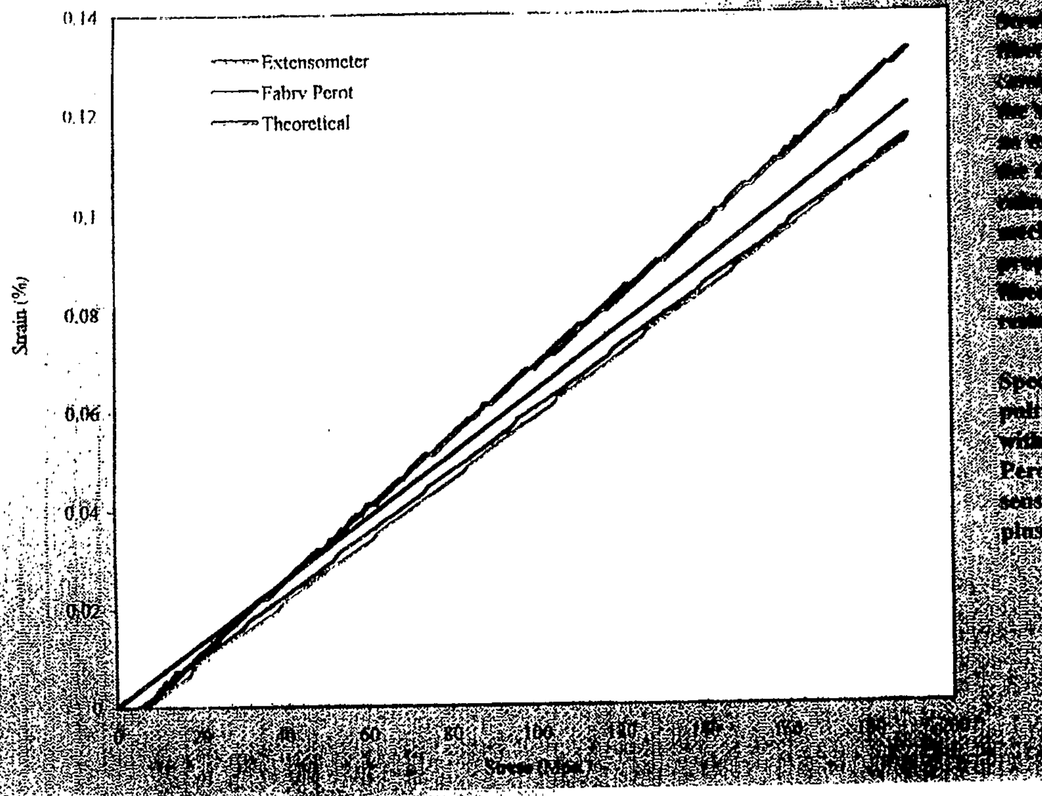


Microstrain versus Load

Strain from a Bragg Grating Sensor embedded in a glass rod , subjected to a sinusoidal load varying from 0 - 2500 lb with a period of 1 minute. (Measured with FLS 3100.)



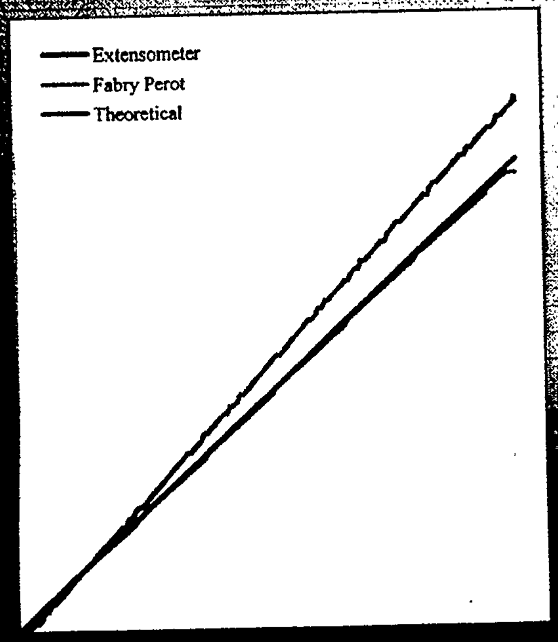
Fiber Optic Strain Sensors Perform Well In The Heat



Strain measured with the fiber optic sensor compares well with both the strain measured using an extensometer and with the theoretical strain calculated using micro-mechanics and the known properties of the carbon fibers and vinylester resin.

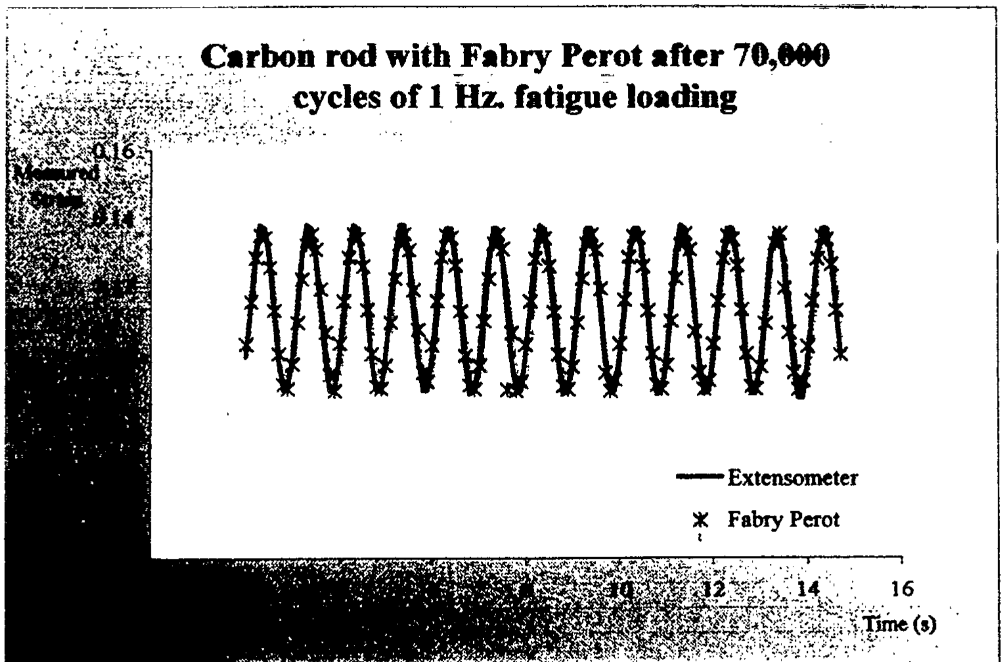
Specimen was a pultruded carbon rod with embedded Fabry Perot fiber optic strain sensor. Testing done at plus 60 deg. C.

Fiber Optic Strain Sensors Perform Well In Extreme Cold



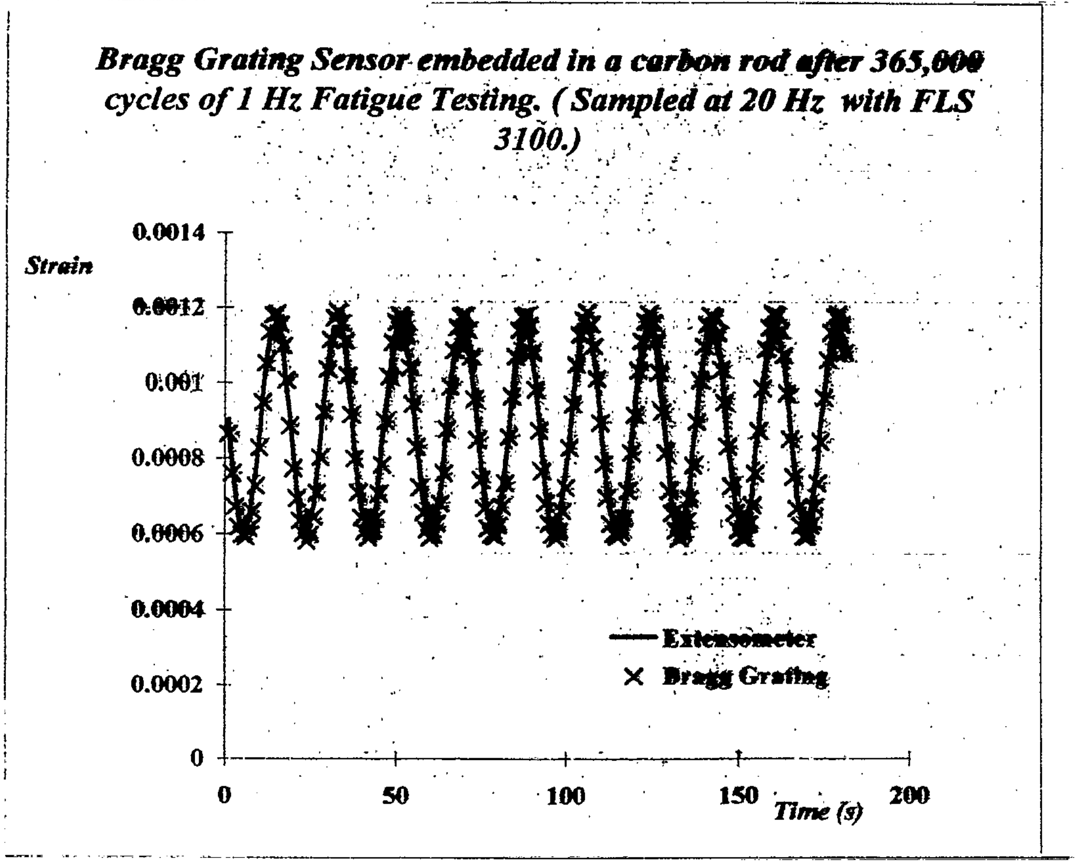
Strain measured with the fiber optic sensor compares well with both the strain measured using an extensometer and with the theoretical strain calculated using micro-mechanics and the known properties of the carbon fibers and vinylester resin.

Specimen was a pultruded carbon rod with embedded Fabry [illegible] C.



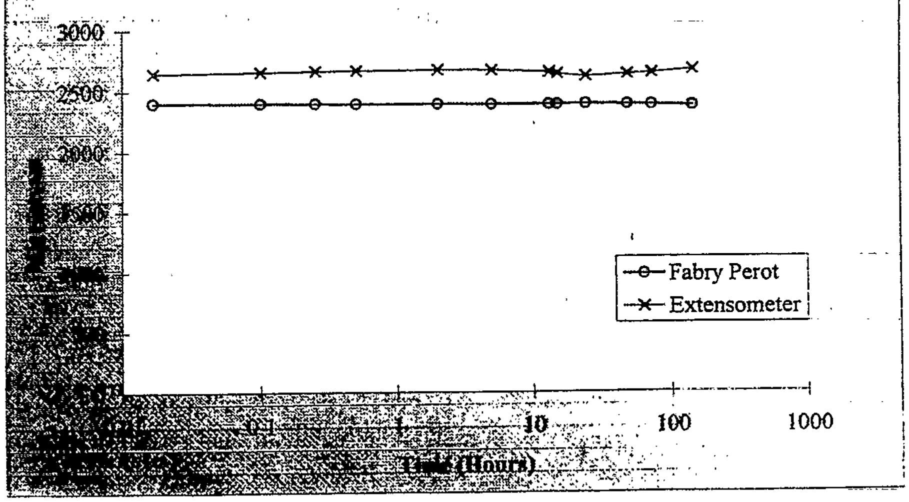
Carbon rod with Fabry Perot after 70,000 cycles of 1 Hz. fatigue loading

Comparison of the strain in a carbon fiber reinforced rod, measured using an extensometer & a fiber optic sensor after 70,000 cycles of fatigue loading. Load = 2,000 + 500 sin(t x 2 pi) lb.



Bragg Grating Sensor embedded in a carbon rod after 365,000 cycles of 1 Hz Fatigue Testing. (Sampled at 20 Hz with FLS 3100.)

A Glass Fiber Rod with Embedded Fabry Perot Fiber Optic Strain Sensor Gives a Very Stable Reading When Subjected to a 140 Mpa. Continuous Load at Room Temperature.



Harsh Environments

Materials:

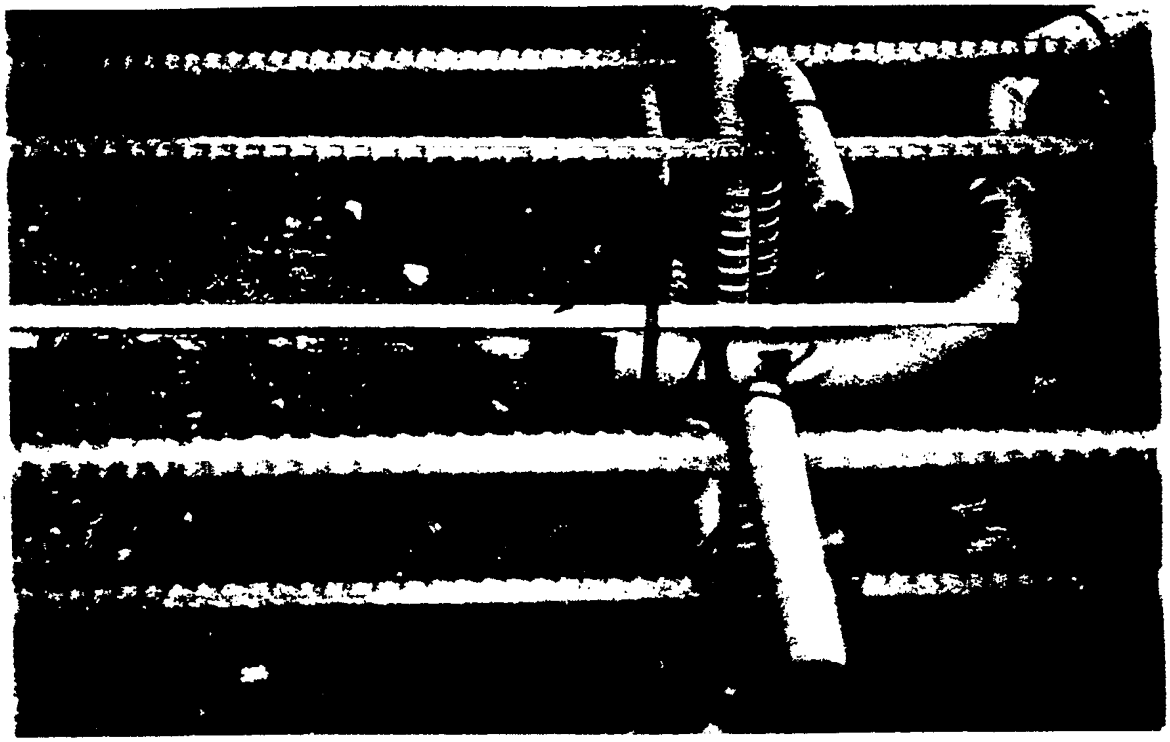
- Steel, GFRP, CFRP, Rebars
- Polyimide, Acrylate Coatings

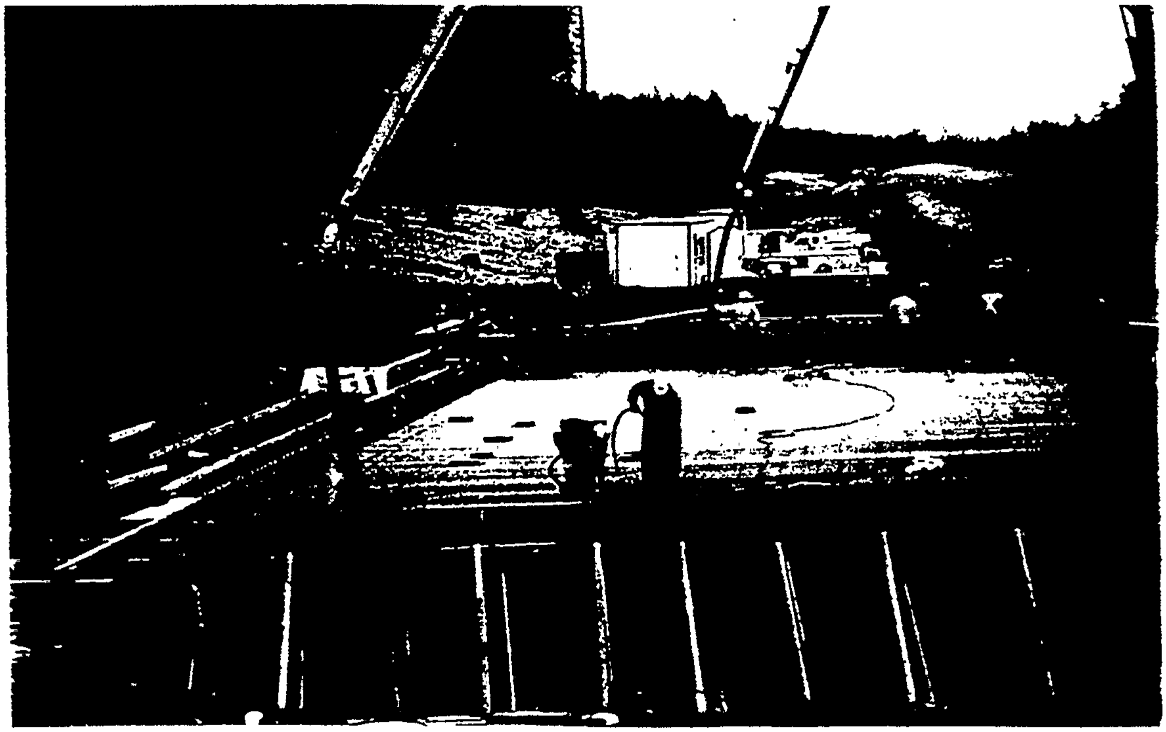
Test Solutions:

- Filtered Seawater
- Simulated Concrete Pour Water: pH 13

WATERLOO CREEK BRIDGE

Vancouver Island, British Columbia





Conclusions to Date

Fabry Perot and Bragg Gratings:

- Survive pultrusion process.
- Provide strain data comparable to externally affixed devices.
- Function over wide range of temps.
- Reliable under sustained loadings.
- Reliable after many load cycles.