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MONITORING OF FATIGUE CRACK PROPAGATION BY MEANS OF FIBER OPTIC SENSOR

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1. INTRODUCTION

Fiber optic sensor offers a number of advantages with respect to electrical sensors and will open up the opportunity for many new systems to be developed in smart technology. The lightweight, small size of fiber sensors are strongly complemented by their strong immunity to electromagnetic interference and huge data transmitting capability make its position stronger as a tool for structures integrity monitoring. Fatigue is the most common cause that impairs structure's serviceability. Our objective is to apply these sensors as a integrated part of structure that will measure internal deformation due to load and environment during service. In our previous experiments we monitored crack propagation of invisible part of structure by ultrasonic testing [1]. From ultrasonic scanning images, it was clear that crack tip elongated at higher loading cycles and strong reflection gradually appeared far from notch tip indicated that crack has propagated [2]. These data will provide us information about present condition of existing structure for maintenance and rehabilitation cost effectively.

2. EXPERIMENT

We attached FOS (Fiber Optic Sensor) and SGS (Strain Gage Sensor) on probable crack propagation area for strain measurement. Repeated loading were done for crack initiation and propagation. Test performed for comparison of FOS and SGS output and measurement accuracy.

2.1 EFPI Sensor The extrinsic Fabri-Perot interferometer (EFPI) sensor head and a schematic diagram showing functionality of the absolute fiber-optic

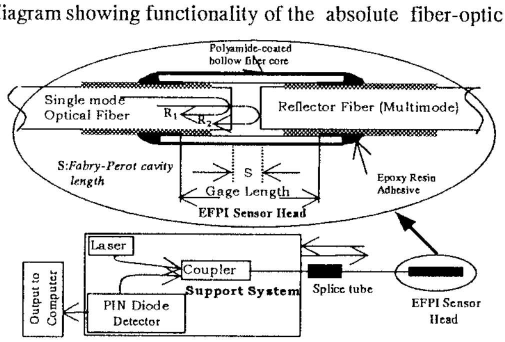

Fig. 1 AFSS with FOS Head

support system (AFSS-PC) shown in Fig.1. The AFSS-PC sensor system employs a broadband light-emitting diode (LED) as the optical source. A single mode fiber (λ = 1300ηm) used as input/output fiber, and a multimode fiber as reflector. Light is sent down the input / output optical fiber to the sensor head where it is modulated by the Fabry-Perot cavity inside the EFPI and the properties of light are changed by the Fabry-Perot cavity. A simple algorithm is used to determine the Fabry-Perot cavity length, s, from the optical signal returned from sensor head. Sensor specification is illustrated in Table 1.

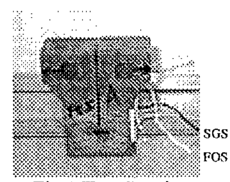

Fig.2 Test Specimen

Table 1 FOS Specifications

Model No.	S-A EFPI	S-E EFPI
Physical Dimension	5 mm length, 1mm thickness and 5mm width	5 mm length, 350 μm outer diameter
Temperature range	-75°c to 200°c	-100°c to 350°c
Strain Range	± 5000 μstrain	± 5000 μstrain
Gage Factor accuracy	0.75%	0.5%
Lead Protection	24 gauge Fiber Glass sheathing	30 gauge Teflon sheathing

2.2 Test Specimen Instrumentation V-notched Y-shaped SS400 steel specimen of 25mm thick instrumented for fatigue loading and strain measurement is shown in Fig.2. Surface is prepared thoroughly degrease with acetone by wetting the entire surface and dried for abrade with sandpaper. After wiped with cotton gauze to remove any impurities and fixed FOS and SGS 2mm far from notch tip in opposite side by adding adhesives to the sensor base and specimen.

2.3 Fatigue Loading Fatigue loading performed with hydraulic equipment of survo-pulser unit that subjected the specimens to tensile loading. Before loading all specimens were scanned to get image of notch tip area. Then sinusoidal wave cyclic loading done under constant load range of 5.0KN~1.0KN and of frequency 10Hz. During loading after predetermined cycles interval C-scan image and strain data were measured.

2.4 Strain Measurements For strain measurement interrupted the normal loading and strain data measured at various loading frequency of 0.10Hz, 0.25 Hz and 2.0Hz at predetermined cycle interval. FOS used here of zero point 55μm and gage factor of 4.26mm. SGS strain data directly stored as microstrain and FOS strain data measured as absolute displacement and then converted to strain data as microstrain by following equation,

$$strain(\mu strain) = \frac{[Sensor\,Reading - ZeroPoint](\mu m)}{GageFactor(mm)} \ldots (1)$$

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2.5 Applicability Test of FOS Before going to monitoring of fatigue crack we conducted test to observe how FOS and SGS behaves when tension and compression occurs to the attached members. Specimen and loading for 4-point bending test is shown in Fig.3. The compressive load gradually increased to a

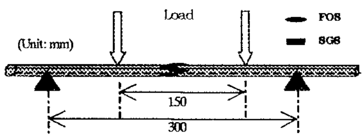

Fig.3 Four-point Bending Test Specimen

predetermined load level and then released with same interval after measuring the strain data. The result is

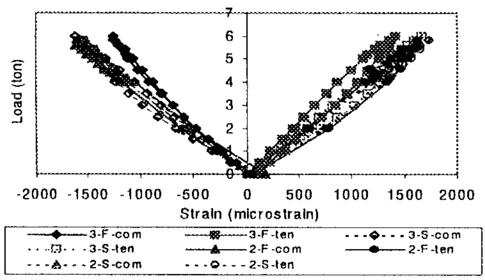

Fig.4 Load vs Strain Curves

illustrated as load verses strain curves in Fig.4.

Thus in the loading step we observed the strain change ratings when greater amplitude load applied. From above results it may conclude that the sensor survived during loading at vibration and in inhomogeneous material like concrete. FOS and SGS shows strain variation within 5% for steel bar specimen and 10~20% for concrete covered steel bar specimen. Which may be due to as the sensor is reused and within embedding into concrete and overlapping load center. After experienced loading when the load released to zero the sensor output also shows zero reading though some residual strain is still existing.

3. RESULTS AND DISCUSSION

Crack tip/notch tip expands and contracts in order to loading amplitude and frequency, then sensor senses these fluctuation and average data represents as strain of the loading cycles. Output for different loading frequencies is shown in Fig.5.

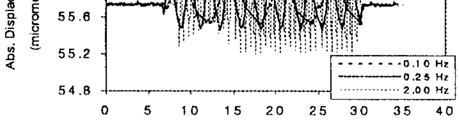

Fig.5 Measured Loading Frequency

When crack proceeded to sensors sensing zone strain variation is observed. Comparison of measured strain for FOS and SGS is shown in Fig.6 (a) and (b). Sometimes negative or compressive strain is observed which may be due to strain response for bond performance between sensor and specimen or crack tip deformation nature. The sudden jump of strain is observed after 7×10^4 cycles is the indication of crack tip deformation. The difference of maximum-minimum strain increases as crack proceeds. Though the protection coating bond of the sensor absorbs a portion of the actual strain. However the strain data is very similar at transition for both sensor in varying frequency. For monitoring it is needed to set allowable strain range and elastic-plastic zone before fracture.

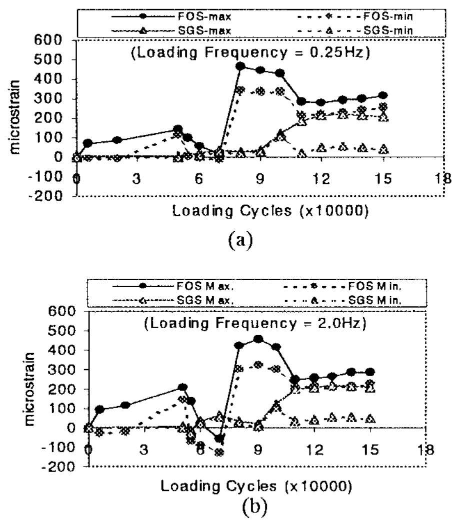

Fig.6 Comparison of Measured FOS and SGS Strain

4. CONCLUSION

The approach of using smart tool for integrity monitoring of structural components is described. Due to cyclic fatigue loading the strain response is also cyclic so maximum and minimum strain data is considered. In this research we introduced new experimental technique for diagnosis of fatigue crack detection and propagation. Fiber optic sensor may use as structures integrated part for long time remote monitoring.

5. REFERENCES

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