DEVELOPMENT OF A "FUZZY FIBER" SENSOR FOR REAL TIME STRUCTURAL HEALTH MONITORING

M. Boehle, Q. Jiang, L. Li, A. Lagounov and K. Lafdi

Carbon Research Laboratory
University of Dayton Research Institute
300 College Park, Dayton, OH 45469

Introduction

Structural Health Monitoring (SHM) seeks to provide ongoing monitoring of a structure's integrity, minimizing the need for programmed inspections and allowing maintenance to be need-driven, rather than usage-driven. Current SHM approaches often use strain gages, accelerometers, and more recently, piezoelectric sensors. These provide "point" measurements of engineering information; therefore, they must be placed at or near critical regions of interest in order to detect damage. Should damage occur at other unanticipated regions, it may go undetected. Methods have been devised to use the sensors in a network to "triangulate" readings/locations of interest. This is especially true for piezoelectric sensors, which provide an actuation as well as a sensing function [1, 2]. In the end, though, all of these schemes rely on point-wise measurements and have the potential of not detecting damage. The goal of the study is to explore alternative sensing methods that can provide wide-area detection of damage.

Microelectrodes have been utilized for electrochemical sensors for detecting chemicals and biochemicals [3]. Carbon and glass fibers could be used as microelectrodes due to their excellent chemical stability, bioadaptability, mechanical properties, electrical properties, low cost and wide availability. Portable biosensor products utilizing carbon fiber probes are currently available on the commercial market.

Carbon nanotubes and nanofibers (CNTs and CNFs) are increasingly getting attention for their applications in fabricating sensors. They were found to have outstanding ability to mediate fast electron-transfer for a wide range of electroactive species, enhance electrochemical reactivity, accumulate important biomolecules and alleviate surface fouling of electrodes [4, 5]. They also have large length-to diameter aspect ratios that can provide high surface area for depositing external materials or performing functionalization for electrodes used for a variety of applications.

Electrodes were fabricated using carbon or glass fiber with CNTs uniformly attached by low cost thermal chemical vapor deposition (CVD). Figure 1 shows an SEM image of a CNT fuzzy fiber. The electrical resistivity of the fuzzy fiber is altered by any mechanical or chemical stress (strain, cracks, adsorption of molecular species, aging, etc.). The brittle nature of glass fibers might be suitable for the detection of crack initiation and propagation.

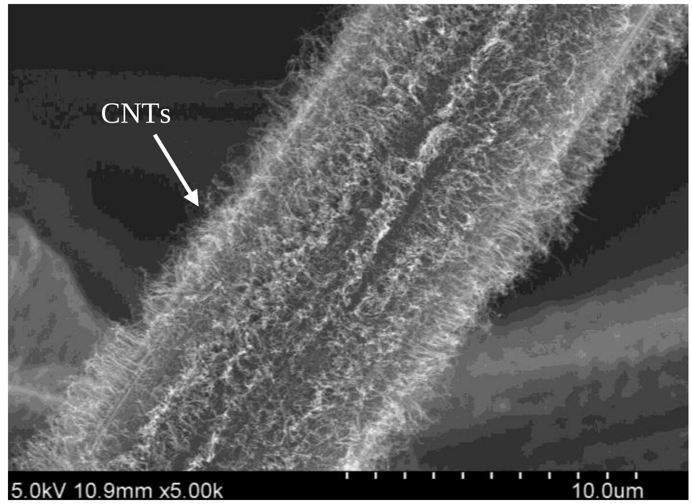

Fig . 1 SEM image of a fuzzy fiber sensor.

Experimental

A specially designed tension stage was built which provided the ability to perform tension tests on a single fuzzy fiber. Figure 2 shows an overview of the stage. The stage provides .75 micron displacement resolution and a maximum load of 50 grams.

Fig . 2 Time Single fiber tension testing stage.

The two halves of the sample plate, where the fuzzy fiber is attached, are coated with epoxy to electrically insulate them from each other. A small drop of silver filled epoxy was placed on top of the epoxy on each half of the sample plate. Before the silver filled epoxy had cured, the fuzzy fiber was pushed into it, so that the fiber bridged the gap between the two halves of the sample plate. A copper wire was also pushed into each drop of silver filled epoxy, which provided the ability to measure the resistance of the fuzzy fiber before and during the test.

The tension stage was placed in an optical microscope, which provided the ability to record a video of each test using the digital camera on the microscope. The microscope images were used to observe the test and validate it by ensuring that the fiber was not slipping in the epoxy and that the electrical resistance jumped to infinity at the instant the fiber failed, showing that the recorded strain and resistance values were correct. Figure 3 shows a time series of stills taken from a video of one test. The pictures show the initial position, the position during the test and the final position where the fiber failed. At this point, the load dropped to zero and the resistance went to infinity.

The stage was controlled using a custom Labview application, which provided the displacement drive signals and recorded the load data. The resistance data was recorded separately using a Keithley 2700 multimeter. Timestamps were used to synchronize the two data sets after each test was performed.

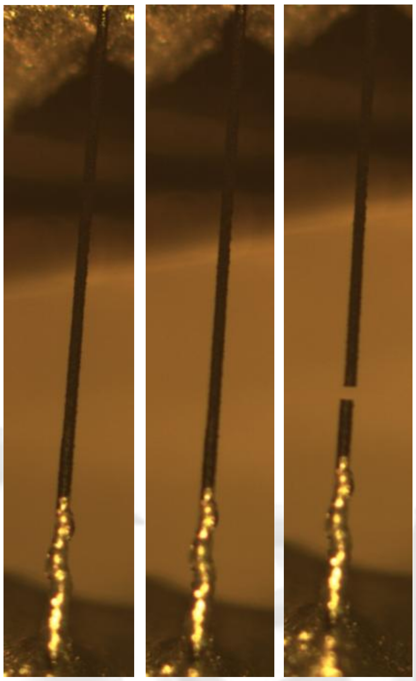

Fig . 3 Time series of hybrid fiber strain sensor under test.

Results and Discussion

The tension tests provided the load and displacement data, as well as the resistance data. Figure 4 shows typical data of the tension tests. The data shows that the resistance changes with the load. This correlation between the strain and change in resistance demonstrates the ability of the hybrid fiber to sense strain.

To assess the sensitivity of the hybrid fiber sensor, the gage factor was calculated. The gage factor for most metallic strain ages is around two. The gage factor for the hybrid fiber sensor is approximately twice that of a metallic strain gage. The higher gage factor of the hybrid fiber sensor means that it can detect smaller strains and provides a larger electrical response, which makes data acquisition more reliable.

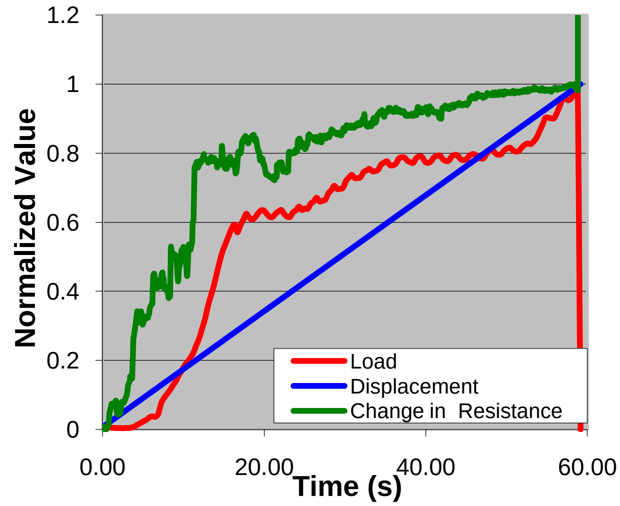

Fig. 4 Tension test results for a Hybrid Fiber strain sensor.

Conclusions

Fuzzy Fibers have been shown to be effective strain sensors. Their electrical response provides increased sensitivity over metallic strain gages and the small size of the fuzzy fiber sensors makes it easy to embed them within composite structures. Fuzzy fibers of several meters in length can be fabricated, which will provide wide area strain sensing, as well as detection of cracks. The fuzzy fiber strain sensor will find application in the aerospace, performance marine and wind energy markets, where the heavy use of composite materials dictates the need for SHM. Fuzzy fiber sensors allow engineers to assess the integrity of the structure and repair or replace critical components which are showing signs of structural damage. Embedded sensors will reduce costs by increasing the service life of components and allowing maintenance procedures to be performed before catastrophic failure occurs.

Acknowledgments. This work was supported by US Airforce AFOSR funds under contract number FA9550-09-1-0686.

References

[1 Andrews, J., A. Palazotto, M. DeSimio, and S. Olson, “Lamb Wave Propagation in Varying Isothermal Environments”, accepted March 2008 for publication in *Structural Health Monitoring*, 2008.

[2] Olson, S., M. DeSimio, K. Brown, and M. Derriso, “Impact Localization in a Composite Wing Structure,” proceedings of the Sensor, Signal and Information Processing workshop, Sedona, Arizona, May 2008.

[3] T. Kohma, D. Oyamatsu, S. Kuwabata, Electrochemistry Communication, 9 (2007) 1012-1016. [4] Joseph Wang, Electroanalysis, 17 (2005), 7-14

[5] Li, Lingchuan and Lafdi Khalid sensors & Acuators: B. Chemical, Vol 132, pp. 202-208 (2008).