CAAP Quarterly Report

Date of Report: *October 10, 2019*

Contract Number: 693JK31850012CAAP

Prepared for: *USDOT Pipeline and Hazardous Materials Safety Administration (PHMSA)*

Project Title: *Magnet-assisted Fiber Optic Sensing for Internal and External Corrosion-induced Mass losses of Metal Pipelines under Operation Conditions*

Prepared by: *Missouri University of Science and Technology (Missouri S&T)*

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For quarterly period ending: *September 30, 2019*

Business and Activity Section

(a) Generated Commitments – Dr. Genda Chen directed the entire project and coordinated various project activities.

Dr. Liang Fan and Mr. Chuanrui Guo, a Ph.D. in civil engineering at Missouri S&T, were on board since the beginning of this project. They are responsible for the fabrication and characterization test of sensors under Dr. Chen's supervision.

(b) Status Update of Past Quarter Activities – Detailed updates are provided below by task.

Task 1 Optimization of a magnet-assisted hybrid FBG/EFPI sensor enclosed in a plexiglass container for simultaneous measurement of temperature and pipe wall thickness

As shown in Figure 1, a hybrid extrinsic Fabry-Perot interferometric (EFPI) and fiber Bragg grating (FBG) sensor sits on the top surface of steel plate that is 9.5 mm thick to simulate a X65 steel pipe. Figure 1 shows the set of corrosion tests. Specifically, the steel plate is connected to the positive pole of the power supply, and the graphite rod is connected to the negative pole of the power supply. A constant current was supplied to uniformly corrode the bottom surface of the steel plate, which can be seen as to simulate the internal corrosion of pipeline. When the steel plate becomes thinner, the magnetic force between the steel plate and the magnet is changed. Simultaneously, the cavity length between the end face of the cleaved fiber segment and the gold-coated glass is changed. Therefore, the cavity length change can be used to monitor the corrosion of steel plate. Figure 2(a) shows that the cavity length decreases with the increase of testing time (steel corroded time). Figure 2(b) shows that the steel plate thickness loss gradually increases with the decrease of cavity length. The test results are fitted with a polynomial function to the 3^{rd} order, which can be used to predict the pipe wall thickness loss in the whole life cycle.

Figure 1. Accelerated corrosion test of the steel plate with a round magnet placed on its top through springs.

(a)

(b)

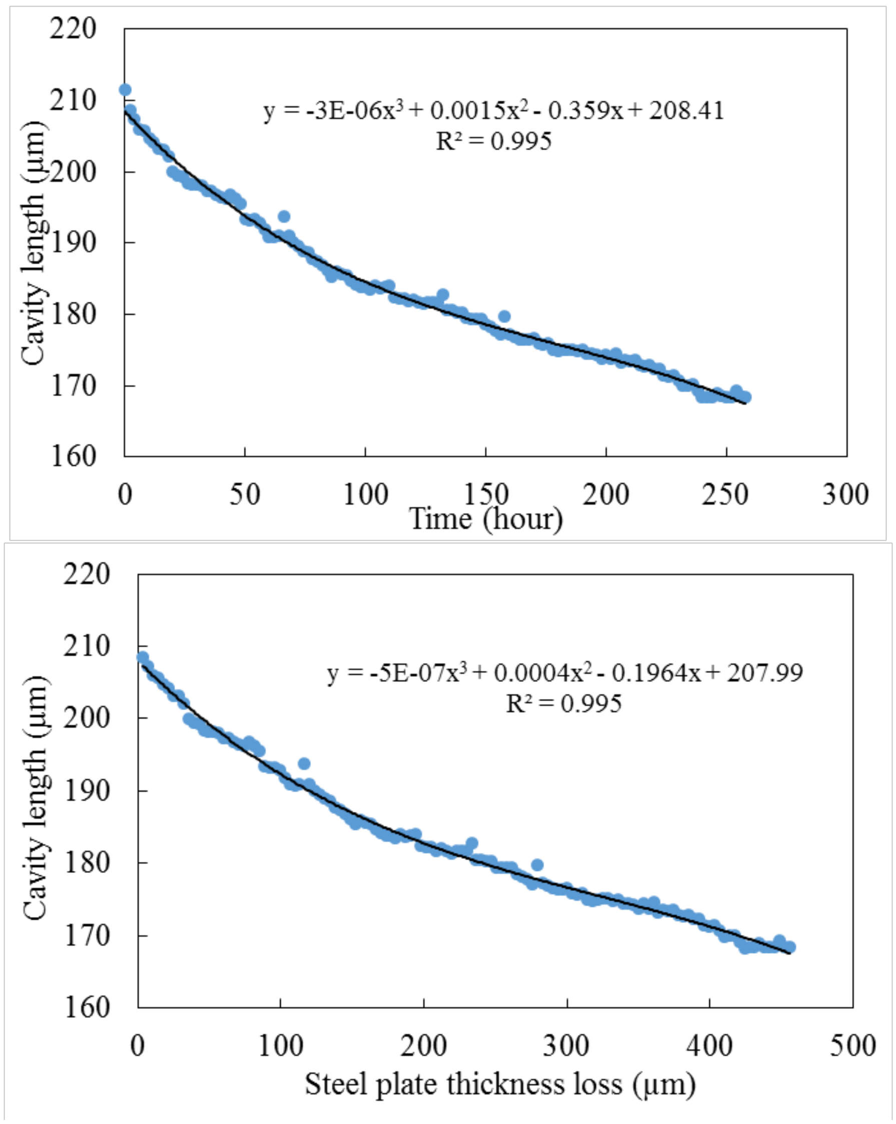

Figure 2. Change of cavity length with (a) the testing time (steel corroded time); (b) steel plate thickness loss.

Figure 3 shows the second device with a rectangular magnet placed on top surface of the steel plate through springs. This assembled device is more stable for steel pipe corrosion monitoring. In this sensor, two EFPI sensors are used. Figure 4 and Figure 5 show the test results of cavity length vs. time and cavity length vs. steel plate thickness loss for EFPI sensor 1 and EFPI sensor 2, respectively.

Likewise, the cavity length and the steel plate thickness gradually decreases with test time. The test results are fitted with another polynomial function to the 3rd order, which can be used to predict the pipe wall thickness loss in the whole life cycle.

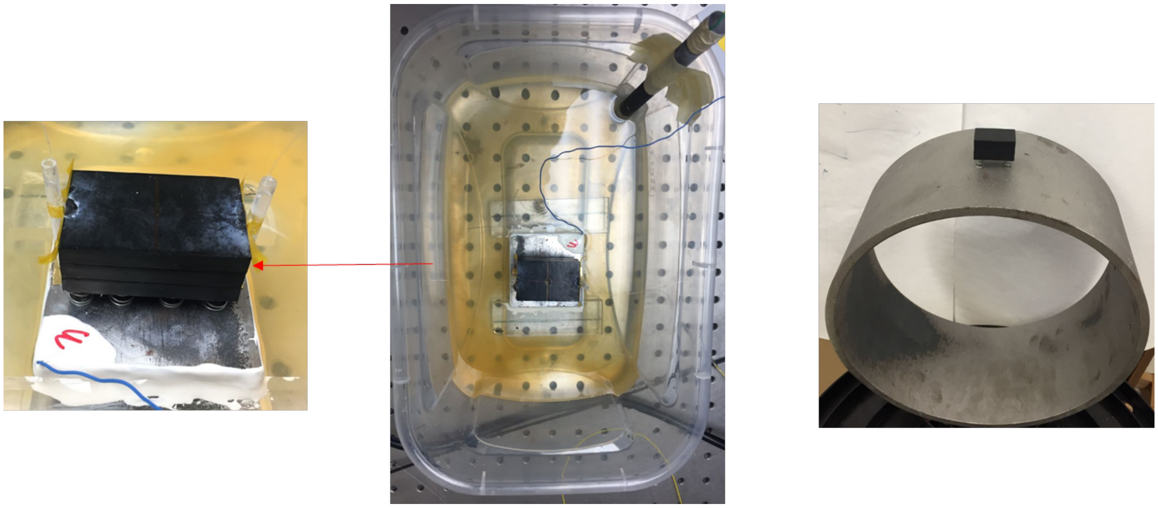

Figure 3. Accelerated corrosion test of the steel plate with a rectangular magnet placed on its top through springs.

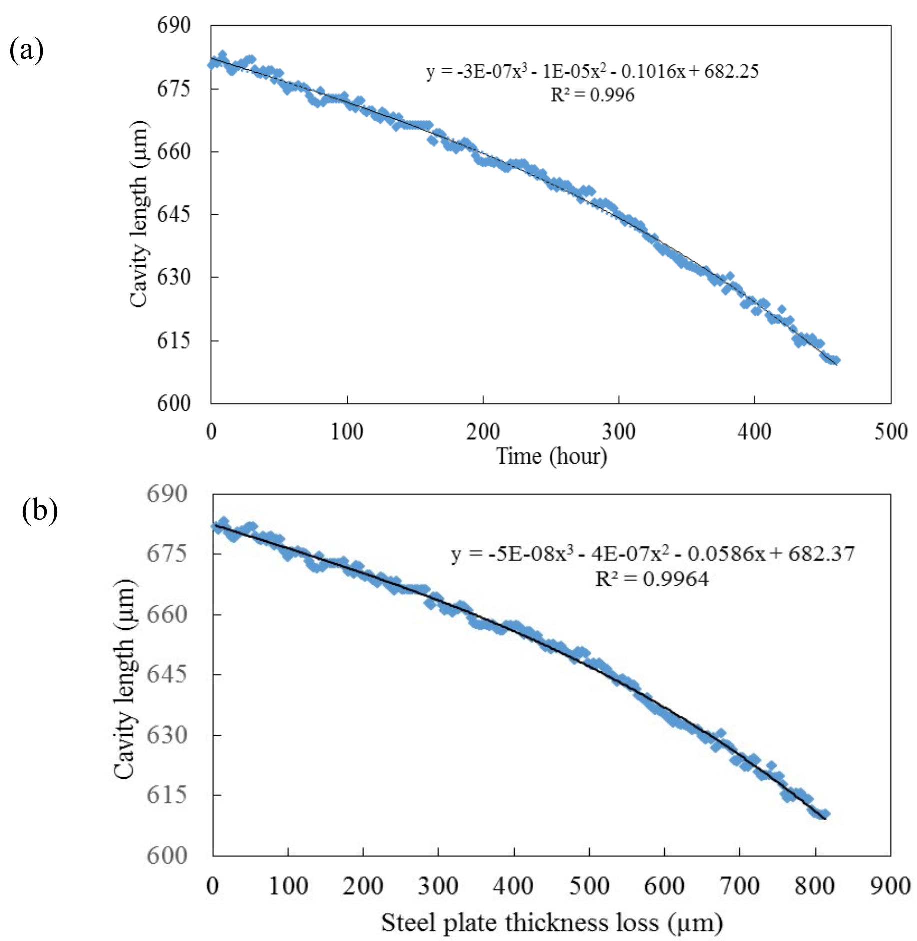

Figure 4. Change of cavity length from EFPI Sensor 1 with: (a) the testing time (steel corroded time); (b) the steel plate thickness loss.

(a)

(b)

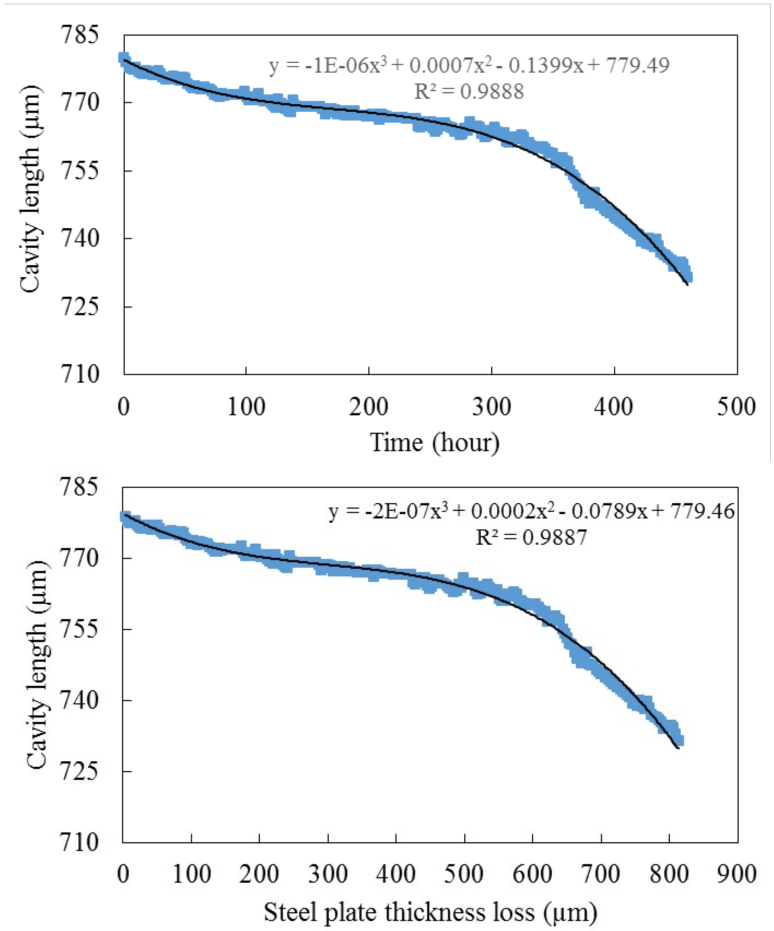

Figure 5. Change of cavity length from EFPI Sensor 2 with: (a) the testing time (steel corroded time); (b) the steel plate thickness loss.

Task 2 Development and validation of a graphene-based LPFG sensor with Fe-C coating for improved sensitivity in mass loss measurement in varying temperature environment

LPFG is a light loss element with the refractive index of a fiber core periodically modulated. It has the capability of sensing the refractive index shift of its surrounding medium. Figure 6 shows the Fe-C coated LPFG sensor for corrosion induced mass loss measurement. A Fe-C layer was coated on the surface of LPFG with silver or graphene-silver nanowire (Gr/AgNW) composite as a conductive film for Fe-C electroplating. The Gr/AgNW composite film grew on a copper foil, wet transferred and adhered to the curve surface of the fiber optic sensor under atmospheric pressure and heating conditions. Both sensors with silver and Gr/AgNW conductive films were tested for 72 h in 3.5 wt. % NaCl solution with simultaneous measurements of transmission spectrum and electrochemical impedance spectroscopy.

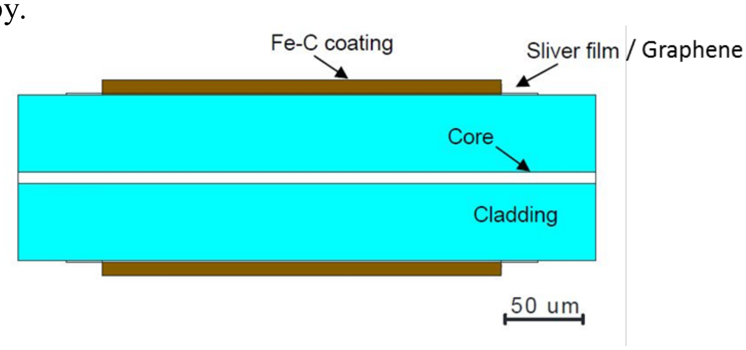

Figure 6. Fe-C coated LPFG sensor for corrosion induced mass loss measurement.

Figures 7(a) and 7(b) show the transmission spectra of Fe-C coated LPFG sensors based on the Gr/AgNW and silver films, respectively, over 72 h of immersion in 3.5 wt. % NaCl solution (1 spectrum every 2 h). The range in spectral shift of the Gr/AgNW-based sensor is significantly larger than that of the silver-based sensor. The blue shift of transmission spectra of the Gr/AgNW-based sensor is steady with increasing bandwidth over time. Figure 7(c) and 7(d) show the wavelength and transmission shifts of the Gr/AgNW- and silver-based LPFG sensors over time, respectively. For the silver-based sensor, the wavelength shift starts after about 10 h of immersion and becomes saturated after 30 h. For the Gr/AgNW-based sensor, the wavelength continues to decrease till approximately 46 h of immersion. The service life (wavelength changing duration) of the Gr/AgNW-based sensor is 210% times that of the silver-based sensor. Figure 7(d) also indicates that the transmission of the Gr/AgNW-based sensor increases steadily till 46 h of immersion while that of the silver-based sensor remains nearly constant till 30 h and changes over time.

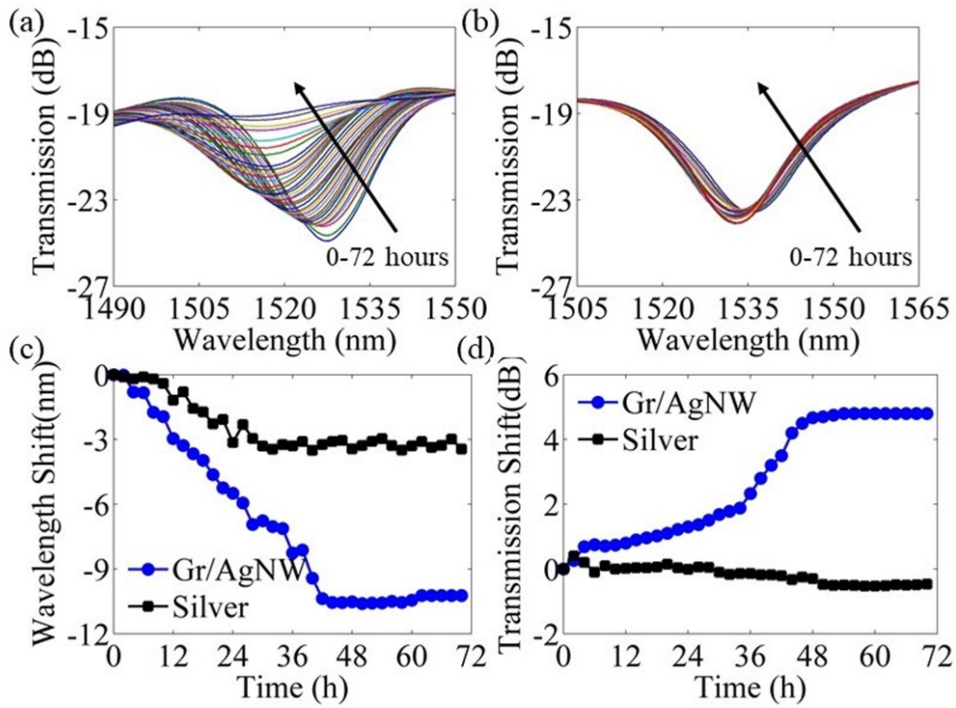

Figure 7. Fe-C coated LPFG sensors in 3.5 wt.% NaCl solution for 72 h: (a) transmission spectra of Gr/AgNW-based film, (b) transmission spectra of silver-based film; (c) wavelength over time, (d) transmission shift over time.

The wavelength and transmission shifts in Figures 7(c) and 7(d) were converted to Figures 8(a) and 8(b) as a function of mass loss of the Fe-C layer. The Gr/AgNW-based and silver-based LPFG sensors with Fe-C coating responded to corrosion process of the Fe-C coating in three stages: (I) gradual, (II) rapid and (III) stable. All linear regression lines are well correlated with test data. A LPFG wavelength shift of 10.3 ± 0.3 nm was achieved with the use of the Gr/AgNW film and 3.4 ± 0.1 nm with the silver film. Similarly, a LPFG transmission shift of 4.9 ± 0.2 dB with the Gr/AgNW film and 0.8 ± 0.1 dB with the silver film were achieved. The Gr/AgNW composite increased the wavelength sensitivity and service life of a Fe-C coated LPFG sensor.

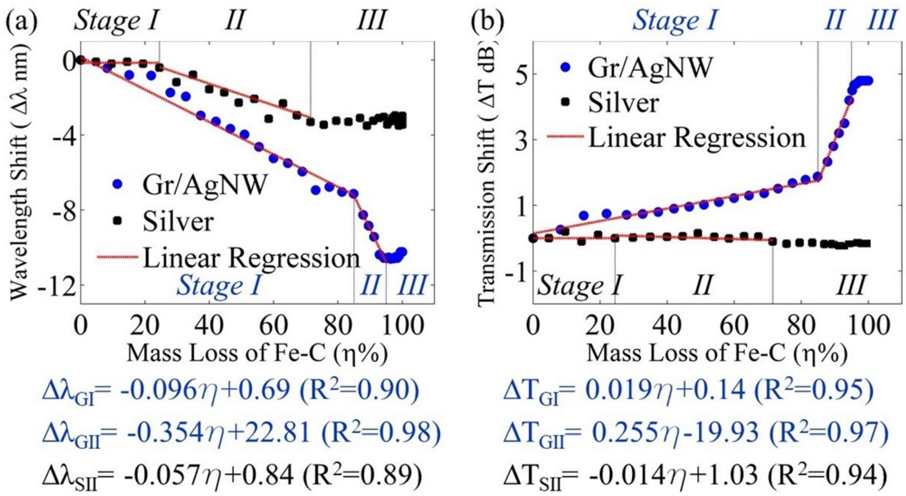

Figure 8. Comparison of wavelength and attenuation shift with Fe-C mass loss between the Gr/AgNW and silver films.

Task 3 Integration and field validation of multiple FBG/EFPI and multiplexed LPFG sensors for internal and external corrosion monitoring of a pipeline with temperature compensation.

This task will not start till the 2st quarter in 2020.

***(c)* Planned Activities for the Next Quarter** - The following activities in Task 1 will be executed during the next reporting quarter.

Task 1 Optimization of a magnet-assisted hybrid FBG/EFPI sensor enclosed in a plexiglass container for simultaneous measurement of temperature and pipe wall thickness

The effect of electromagnetic interference on the hybrid sensor due to DC current will be studied.

Task 2 Development and validation of a graphene-based LPFG sensor with Fe-C coating for improved sensitivity in mass loss measurement in varying temperature environment

The evanescent field attenuation will be characterized. The effect of temperature on the corrosion process and mechanism of Fe-C coating will be investigated.