CAAP Quarterly Report

Date of Report: <*January* 15, 2017>

Contract Number: <DTPH56-15-H-CAAP06>

Prepared for: <Government Agency: U. S. DOT PHMSA >

Project Title: <*Mitigating Pipeline Corrosion Using A Smart Thermal Spraying Coating System*>

Prepared by: <North Dakota State University>

Contact Information: <Dr. Fardad Azarmi, Email: fardad.azarmi@ndsu.edu, Phone: 701.231.9784; Dr. Ying Huang, Email: ying.huang@ndsu.edu, Phone: 701.231.7651.>

For quarterly period ending: <*January 15, 2017*>

Business and Activity Section

(a) Generated Commitments

No changes to the existing agreement.

No equipment purchased over this reporting period.

(b) Status Update of Past Quarter Activities

Studies were continued on corrosion detection in soft coatings using embedded fiber optic sensors during this quarter: 1) Further theoretical analysis of the sensitivity study of the fiber optic sensors; and 2) experimental study for corrosion assessment using fiber optic sensors embedded in soft coating. Further efforts will be put on material optimization and thickness design for hard coating and extending the experimental study on corrosion damage localization and characterization in soft coating and composite coating with combined hard coating and soft coatings. The detail progresses, which were completed in this quarter, are presented below:

1) Theoretical study for quantitative corrosion assessment using the embedded fiber optic sensors in soft coating

Based on the previous work reported in last two quarters, an extended study for the corrosion products-adhesive interaction model was performed. In previously proposed model (shown in Fig. 1), the correlation between corrosion severity (corrosion rate) and slope of collected data was well explained theoretically and verified by experiment data.

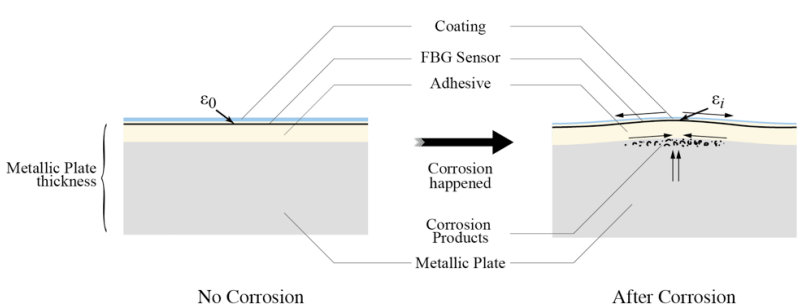


Fig.1 Structural model for corrosion monitoring system

However, in a typical data collected from embedded corrosion monitoring system during experiments, the previously proposed model fails to interpret the quasi-stable section (noted by blue arrow) following the initial wavelength increase (noted by grey arrow).

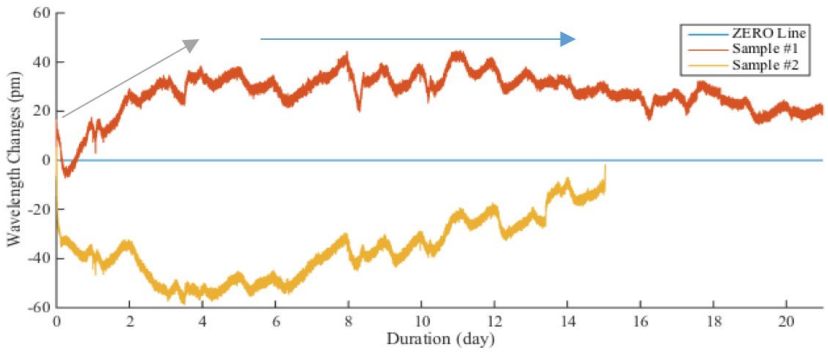


Fig.2 A typical data set collected from embedded sensors

In order to better understanding and express the further development of corrosion, modification of proposed theoretical model is required.

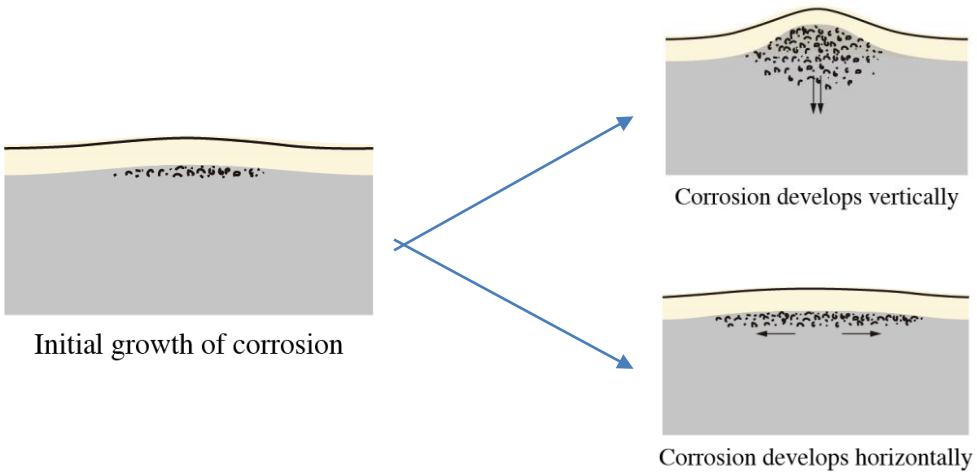
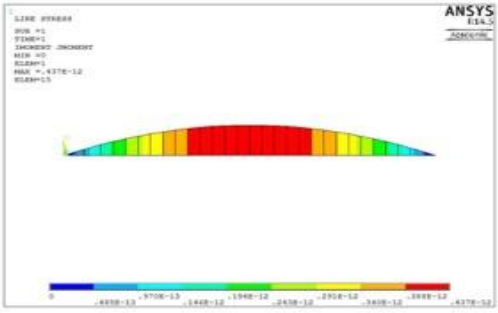
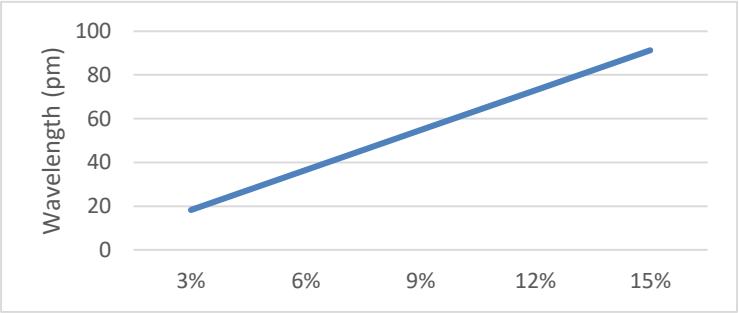


Fig.3 Improved theoretical model for corrosion monitoring system

The modified model for the growth of corrosion will be divided into two parts: i) vertically developed corrosion induced strains; and ii) horizontally developed corrosion induced strains. In previously proposed model, only the strains induced by vertically developed corrosion was considered. Simulation results in Figs.4 (a, b) showed that the simulation results using ANSYS software with considering only vertical pressure induced by corrosion on the embedded sensor. It ends up with infinite increase in wavelength over time, which does not correspond to the experiment results.



(a) Strain distribution



(b) Strain vs sensor wavelength changes

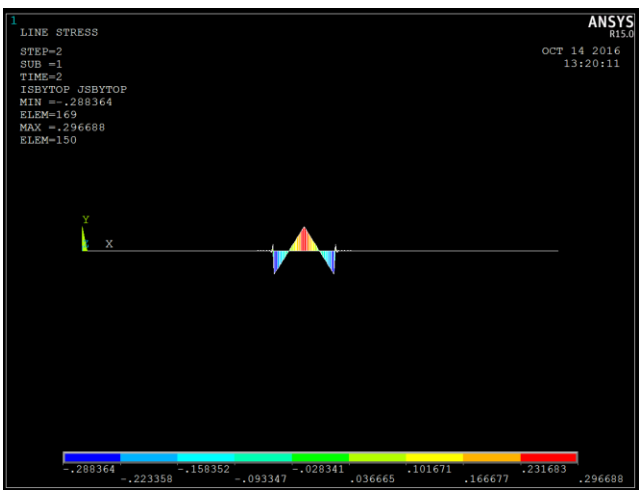
Fig.4 Simulation result for model considering only vertically developed corrosion

Different from vertically developed corrosion, horizontally developed corrosion also influence the horizontal range of corrosion that sensor can detect in addition to the the amount of strains that sensors

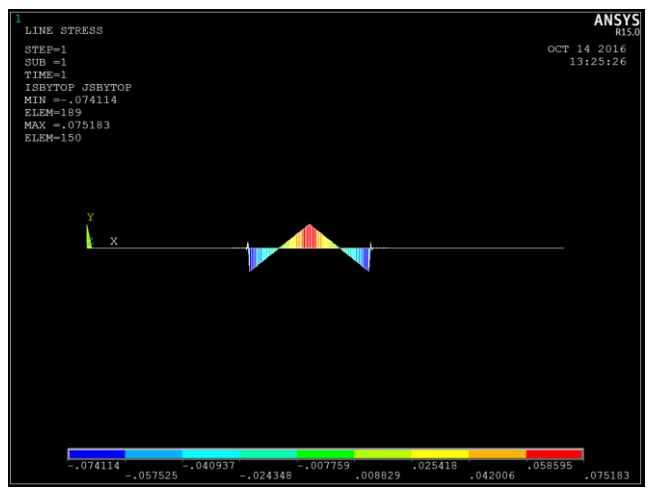
can detect. Fig.5 shows an image after corrosion experiment on a sample with embedded fiber optic sensor. It can be clearly seen that when the corroded length exceeds the sensor length, only partial of corrosion products directly contribute to the strain value detected by FBG sensor.

Fig. 5 Photo showing corrosion developed beyond the length of FBG sensor

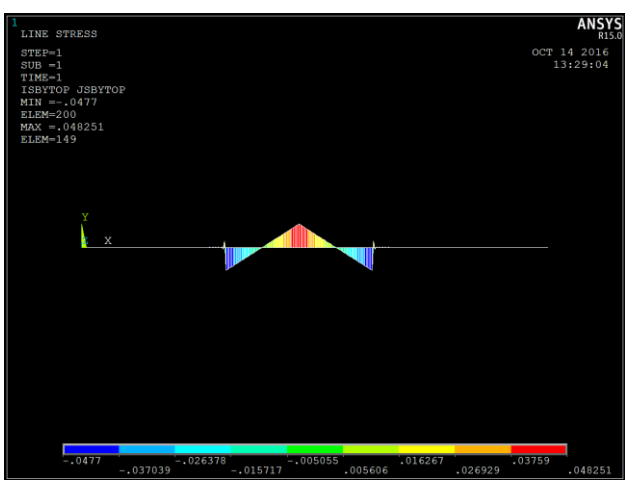
Fig. 6 shows Simulations using ANSYS considering only horizontally developed corrosion show that will the horizontally growth of the corrosion will also cause adhesive detach from base metal in lengthened range in addition to corrosion product production, which further results in strain release. This contributes to the decrease of center wavelength change in embedded sensors.



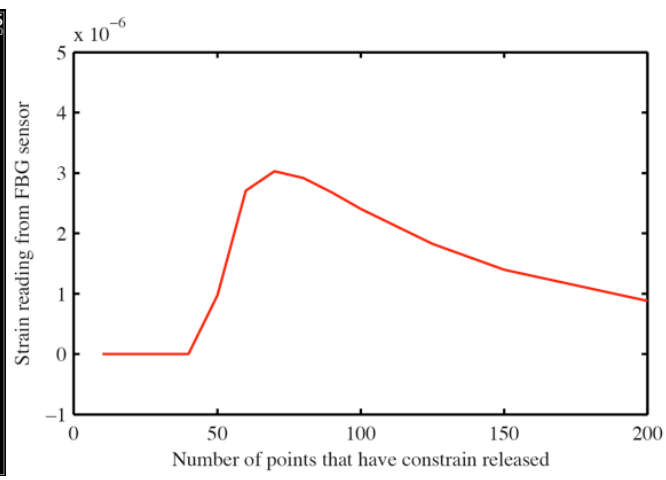
(a) Strain distribution with corrosion < FBG length



(b) Strain distribution with corrosion = FBG length



(b) Strain distribution with corrosion > FBG length



(c) Strains on FBG vs horizontal corrosion

Fig.6 Simulation result for model considering only horizontally developed corrosion

In this quarter, both vertically and horizontal developed corrosion effects were considered to explain fully for the corrosion process on embedded FBG sensors. Fig. 7 shows the simulation results with both vertically and horizontal developed corrosion effects considered. The simulation results showed very close trend when compares to the experimental data (also shown in Fig.7), proving that modified model

well represents the actual corrosion progress under the coating of a practical situation. Thus, the modified theoretical model with both horizontal and vertical corrosion considered will be used in corrosion assessment in future studies.

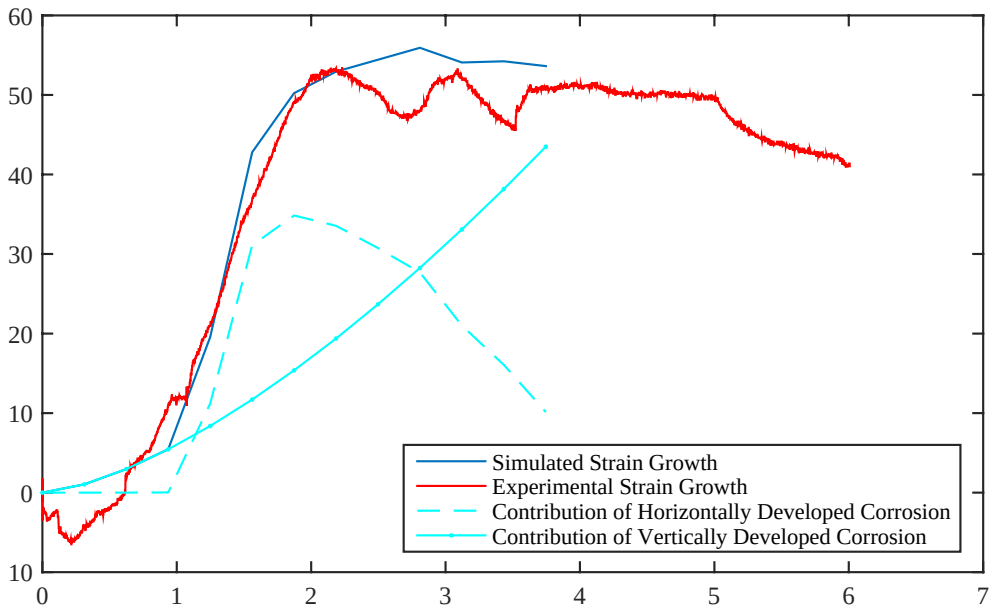


Fig.7 Simulation result considering both vertically and horizontally developed corrosion

2) <u>Experimental data analysis for quantitative corrosion assessment (Task 3 Subtask 3.1)</u>

Three more samples with soft coatings were prepared and accelerated corrosion tests were conducted on them in this quarter (shown in Fig.8 and Fig.9).

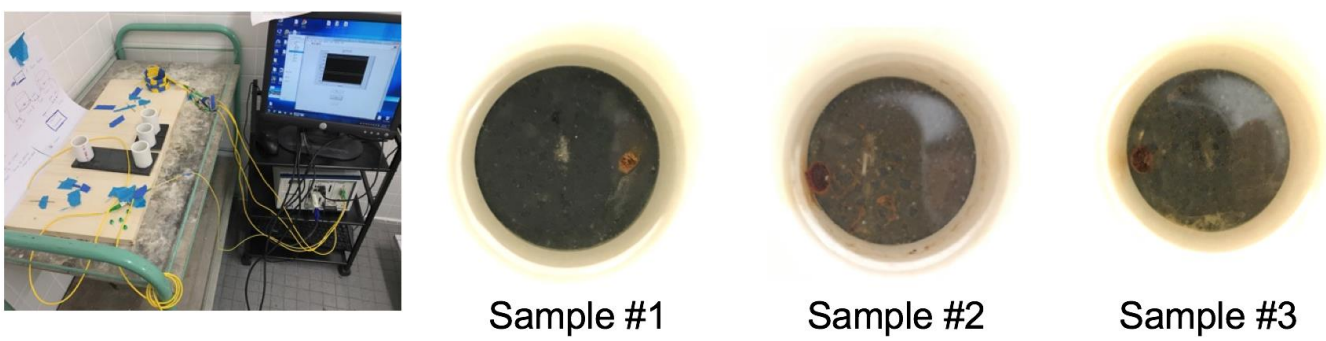


Fig.8 Accelerated corrosion test on three samples with soft coating
(Photos of samples taken on the 7th day as test started)

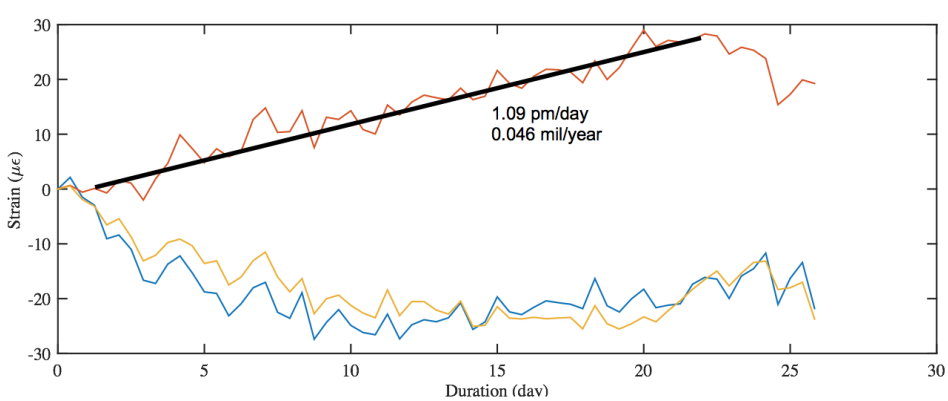


Fig.9 Data collected from embedded corrosion monitoring system

In previous quarterly report, an accelerated corrosion test was also conducted on a sample with soft coating and a pre-made flaw on applied soft coating to shorten the corrosion initialization. The reported corrosion rate of it was 10.76 pm/day. From Fig.9, it can be seen that without any flaw the soft coating can lower the corrosion rate furthermore to 1.09 pm/day. As no significant corrosion develop on top of the sensor, the accelerated corrosion test is still ongoing as the day this report been drafted. Further conclusions will be reported in next quarterly report.

3) <u>Deposition of Al-Zn coating on Steel substrate using Wire Arc Spraying Technology (Task 2 Subtask 2.2 & 2.3)</u>

According to the results from updated materials selection study reported in our previous report, Al-Zn has shown superior corrosion protective combined with acceptable mechanical stability. Wire Arc Spraying technique has also been used to make the coating system more cost effective. Fig.10 shows coatings of Al-Zn deposited on steel substrate at different thicknesses. We will report results of microstructural characterization and corrosion test results on these samples in our next report.

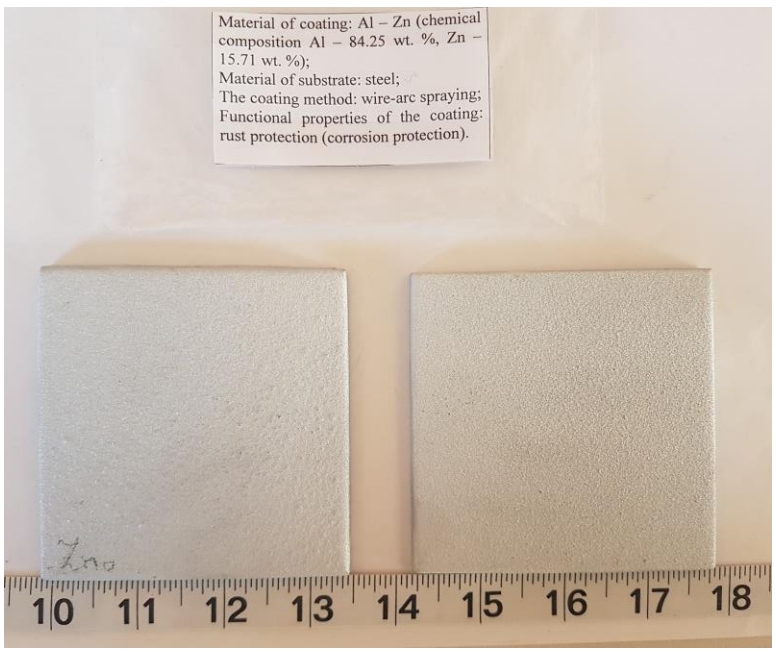


Fig.10 Wire Arc deposited Al-Zn coating on steel substrate, left 2 mm, and right 1 mm.

(c) Description of Problems/Challenges

No challenges encountered this quarter.

(d) Planned Activities for the Next Quarter

The planned activities for next quarter are listed as below:

1) Material characterization and optimization and thickness design for the coating (Task 2.3);
2) Experiment data analysis of monitored soft coating coated steel corrosion progress using the modified theoretic model (Task 3.2);
3) Localize corrosion locations through embedded sensor network (Task 3.2);
4) Corrosion damage characterization (Task 3.2).