CAAP Quarterly Report

Date of Report: <*October* 15, 2016>

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*>

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For quarterly period ending: *<October 15, 2016>*

Business and Activity Section

(a) Generated Commitments

No changes to the existing agreement.

No equipment purchased over this reporting period.

Several different adhesives had been ordered in this quarter.

(b) Status Update of Past Quarter Activities

Several major studies on corrosion detection in soft coatings using embedded fiber optic sensors had been carried out during this quarter: 1) following up study of the corrosion experiment in last quarter, and 2) Experimental data analysis 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 theoretical and experimental study on quantitative corrosion assessment to 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) Following up study of the corrosion experiment in last quarter

Figure 1 shows the experimental setup from last quarter report. After the monitoring of one day, it was found that the performance of adhesive in water as shown in Figure 2 was unacceptable when compared to previous experiments. Water easily broke through the adhesive, causing strain release, it resulted no Bragg wavelength change induced by corrosion. Figure 3 shows the monitored the Bragg wavelength of the two sensors with weak adhesives. It can be seen from Figure 3 that soon after adding 3.5wt% NaCl solution into the attached PVC pipe (recorded as the beginning of the experiment), the compression induced by adhesive started to release very quickly. After that, the residual will be the original compression strain brought by the curing of adhesive. It approves that the adhesive broke quickly after the adding of water and the breakage of the adhesive released the confinement on the embedded sensor. Thus, there is no Bragg wavelength change after the adhesive breakage. This phenomenon validated our hypothesis previously assumed for the principles of the sensor that the strains induced by the corrosion observed from the embedded fiber optic sensors come from the confinement of the adhesive or the coatings. If coating or adhesive is broken, the restrain will be released, and the strain monitored by fiber optical sensor will start to decrease, resulting noticeable Bragg wavelength change. To further approve this concept to explain the monitored fiber optic sensor data, more experiments on soft coatings using epoxy will be carried out in this quarter. Therefore, new adhesive had been ordered in this quarter, and experiment will be conducted again with new adhesive to guarantee a better performance.

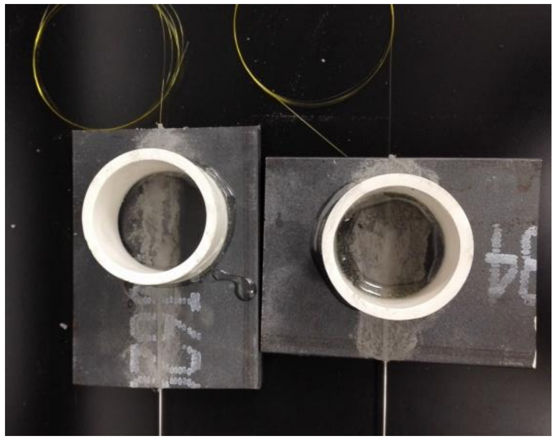
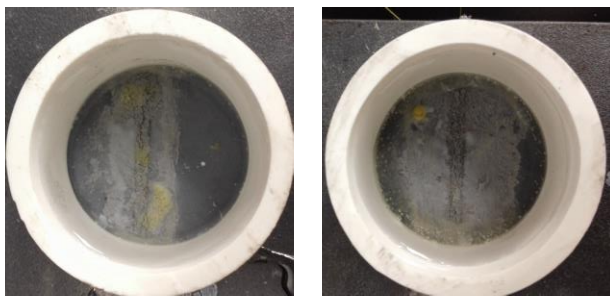


Figure 1 Steel plate samples in previous quarter.



(a) Sample A (b) Sample B

Figure 2 Steel plate samples on the day two for both samples.

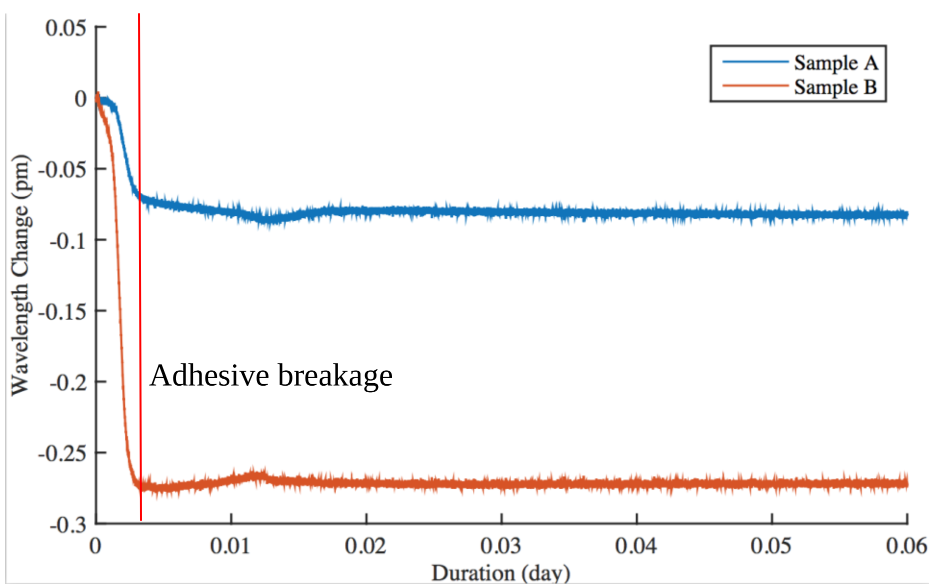


Figure 3 Bragg wavelength change curve of Sample A and Sample B

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

Followed by the theoretical study performed in previous quarter, the concept was further extended to fiber optical sensors embedded in soft coating. The relationship between corrosion rate and the strain induced by corrosion products could be described as follow:

$$\mathrm{CR} = K\frac{d\varepsilon}{dt} \tag{1}$$

In equation (1), K is a parameter related to the coating material and thickness. Ideally, since the theoretical model of the corrosion assessment system would remain in same formation regardless of the change of coating material, even if soft coating instead of hard coating is used in the system, the formula used for calculating corrosion rate from collected strain data of fiber optical sensors would not change. However, a new calibration process is needed for getting correct K parameter. A corrosion test performed on the system with fiber optical sensor embedded in soft coating was carried out to validate this concept.

A36 structure steel was used as base material in the corrosion test, and layer of epoxy (Duralco 4461) was applied on surface of the base material as soft coating. Fiber optical sensor was located between base material and soft coating. After the soft coating layer was fully cured, a PVC pipe with a diameter of 2 inch was fixed on top of the location of sensor by Loctite heavy duty epoxy then filled with 3.5wt% NaCl solution to create corrosive environment for sensing area. To accelerate the corrosion process, a crack on soft coating was made 1 mm besides the sensor, as shown in Figure 4. The crack allows NaCl solution pass through soft coating much faster.

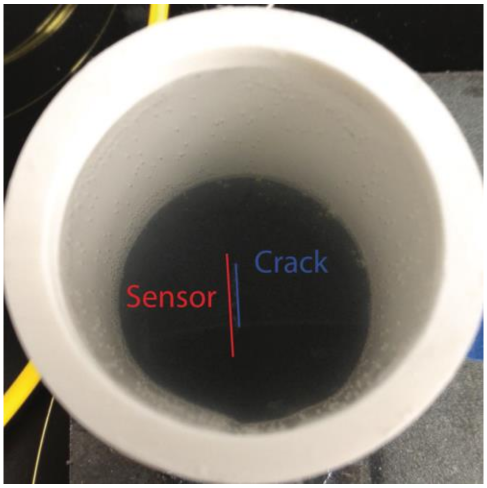


Figure 4 Corrosion experiment set up for steel plate sample with soft coating (Sample #1).

The experiment was finished in 13 days, as a stable strain level was observed after an increase and a decrease were observed in the first 3 days. Figure 5 shows the test results of Bragg wavelength changes versus test time obtained from the embedded fiber optical sensor for the sample.

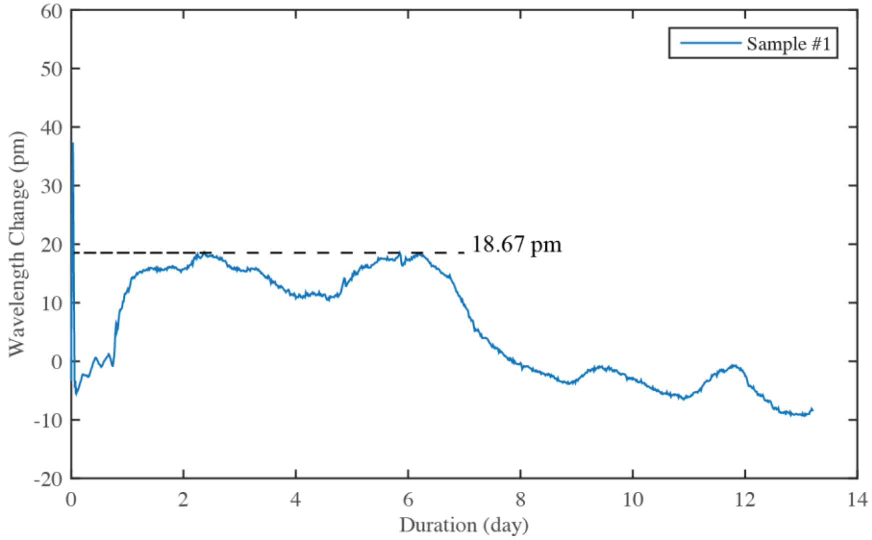
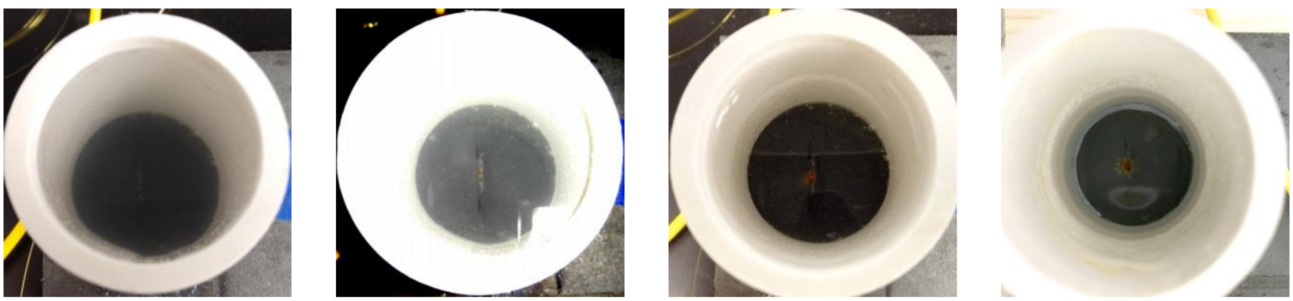


Figure 5 Bragg wavelength change curve of Sample #1.

From the Bragg wavelength changes in Figure 5, it can be observed that highest wavelength change was reached on the second day at 18.67 pm. The wavelength kept staying at same level for 4 days, then started to drop at the day 6. This wavelength change trend indicated the corrosion type should be a pitting corrosion (localized corrosion), and the visual inspection results as showed in Figure 6 to support this inference.



(a) Day1 (b) Day 2 (c) Day 3 (d) Day 6

Figure 6 Visual inspect result of Sample #1.

Figure 5 indicates the Bragg wavelength change rate between the lowest and highest is 10.76 pm/day. Comparing to the data from last quarter, which is 35.19 pm/day as bare steel, it can be seen that the soft coating used in this experiment is able to slow down corrosion process even with a crack on it. However, as crack allows base material expose to oxygen and water in the beginning, the coating failed to protect base material from the initialization of corrosion.

Considering the fact that the chosen soft coating was proven to be effective to slow down and possibly delay the initialization of corrosion process and that fiber optical sensors did work as expected in soft coatings, the future work will be focused on the assessment of corrosion initialization and sensitivity study of fiber optical sensor in soft coating.

(c) Description of Problems/Challenges

Possibility of deposition of optimal selected materials (Al-Mg-Zn-RE) using Wire Arc Spraying technique. To overcome this problem, another round of materials selection will be performed using different steps (Translation, Screening, and Ranking) to select another material with required characteristics. The possibility of being deposited via wire Arc spraying technique will be considered as main criteria during selection process.

(d) Planned Activities for the Next Quarter

The planned activities for next quarter are listed as below:

1) Material selection and optimization and thickness design for the coating (Task 2.2 & 2.3);
2) The sensitivity study of fiber optic sensor for pitting corrosion pattern and studying on model for uniform corrosion pattern with hard coatings and soft coatings (Task 3.1);
3) Localize corrosion locations through embedded sensor network (Task 3.2).