CAAP Quarterly Report

Date of Report: <*October* 10th, 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>

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For quarterly period ending: < *October* 10th, 2017>

<u>Business and Activity Section</u>

(a) Generated Commitments

No changes to the existing agreement.

No equipment purchased over this reporting period.

No supplies purchased in this quarter.

(b) Status Update of Past Quarter Activities

Studies were conducted during this quarter by a comprehensive analyze of the corrosion status of laboratory tested samples with Thermal Spraying Arc Coated Al-Zn coatings for quantitative corrosion assessment using embedded fiber optic sensors (Task 3 Subtask 3.2): 1) experimental setup; 2) experimental data; and 3) data analysis. Further efforts will be focused on more material analysis on Al-Zn coatings, corrosion tests on coating samples with embedded sensors in hard coatings and duplex coatings, and comparison of the different corrosion performance of the coatings toward corrosion. Progress will be made in risk assessment planning based on the corrosion detection. In addition, one more student (Amir Darabi Noferesti) at Masters level has joined our team. He will be responsible on numerical study and finite element analysis (FEA) of coating and pipeline in terms of mechanical properties and corrosion formation. The results of his study can be directly used to predict longevity of coating.

The detail progresses, which were completed in this quarter, are presented below:

<u>1) Experimental setup for Arc wire coated Al-Zn hard coatings with embedded fiber optic sensors (Task 3 Subtask 3.2)</u>

In this quarter, three samples were tested in the laboratory using the same experimental setup as used and explained in previous quarterly reports to evaluate the coating quality and capability of corrosion monitoring system. The three samples were wire arc sprayed Al-Zn hard coating at different thicknesses: 1.5 mm and 2mm. All three coatings were deposited on A36 structure steel. The size of the samples were 2 in. × 2 in. As shown in Figure 1, samples were noted as Sample #A1, #A2, and #A3. The coatings on Sample #A1 and #A2 had thickness of 2mm, and the coating on Sample #A3 had a thickness of 1.5mm. Before the accelerated corrosion test was conducted, PVC pipes were attached on top of each coated sample using epoxy by the same method as tests described in previous quarterly reports to keep consistency, as shown in Figure 2. Figure 3 ilustrated the overall setup for the accelerated corrosion test. The accelerated corrosion test has run for two weeks till the report, and the NaCl solution used in the test has a NaCl concentration of 3.5wt%.

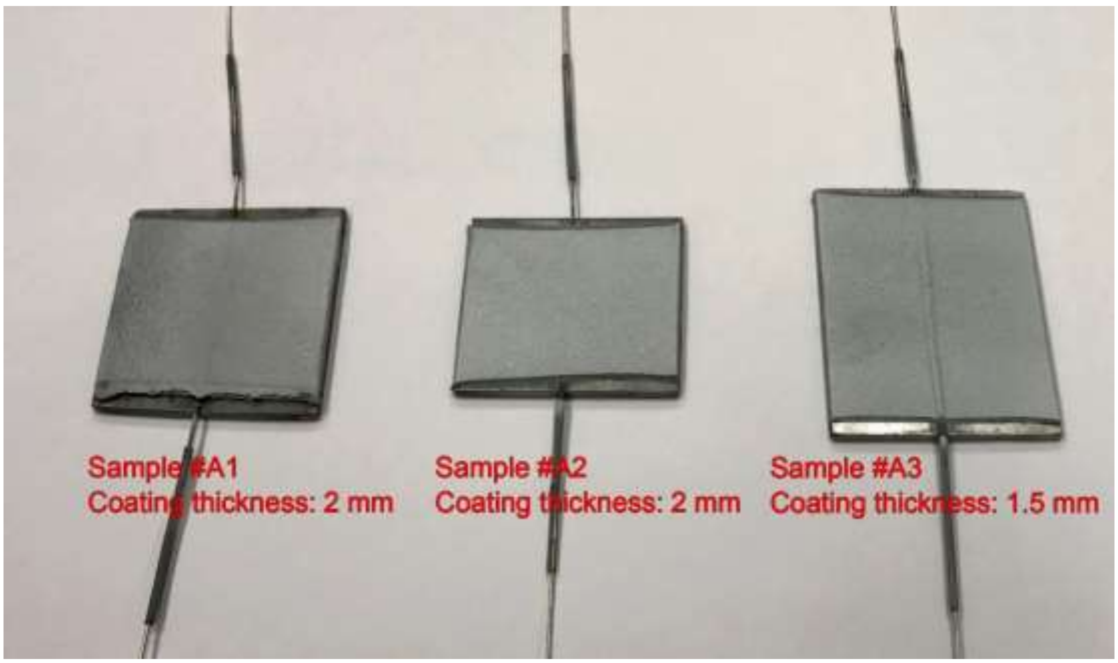


Figure 1. Three Al-Zn coated samples with FBG sensor embedded before test.

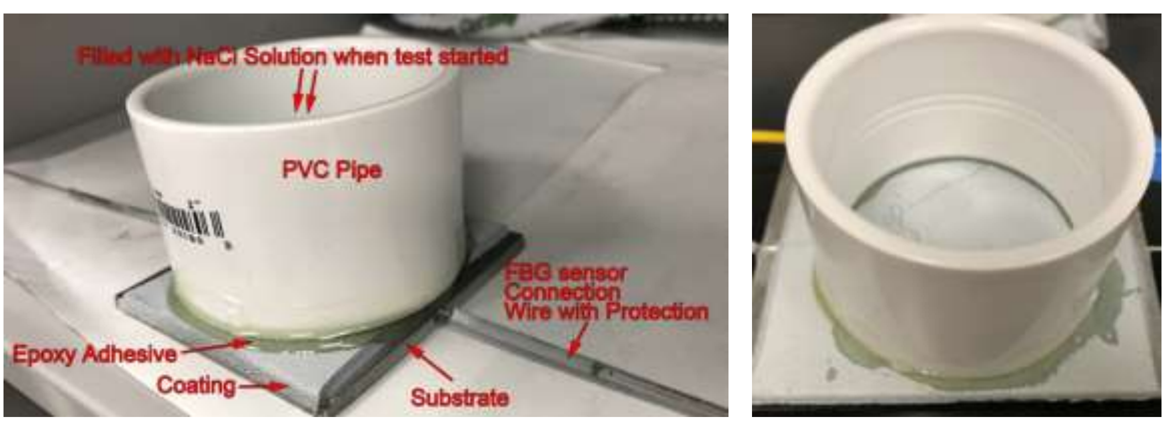


Figure 2. Sample attached with PVC pipe before corrosion test.

Figure 3. Accelerated corrosion test setup.

2) Experimental data from embedded sensors in Al-Zn hard coatings (Task 3 Subtask 3.2)

Figure 4 showed the data collected from embedded FBG corrosion monitoring systems together with the data collected from the temperature compensation sensor during the two-week period (14 days). The data after temperature compensation is shown in Figure 5.

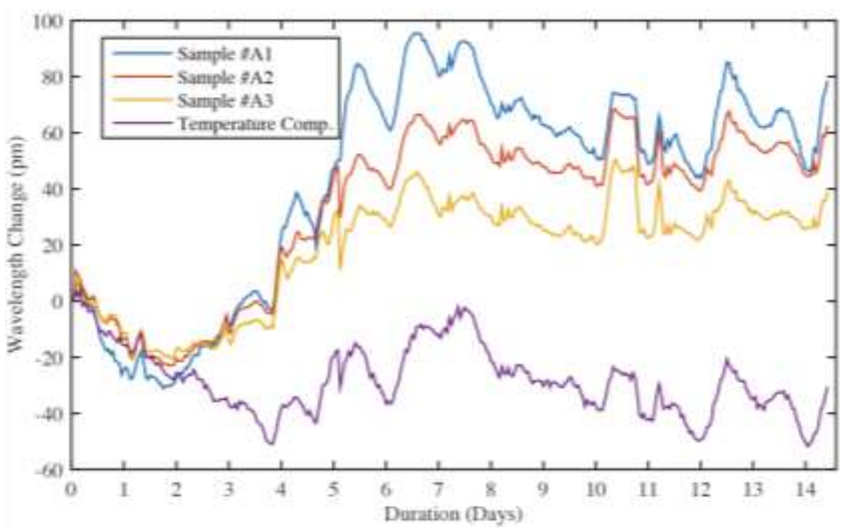


Figure 4. Bragg wavelength changes collected from FBG sensors with *Al-Zn hard coating* without eliminating temperature effect.

3) Data analysis (Task 3 Subtask 3.2)

From Figure 5, the corrosion rate for each coated sample could be calculated by using the methods developed previously and reported in the past quarterly reports, and the detailed calculation results were shown in Table 1 and Figure 6. Corrosion rates listed in table were calculated with scaling factor calibrated with electrochemical corrosion test.

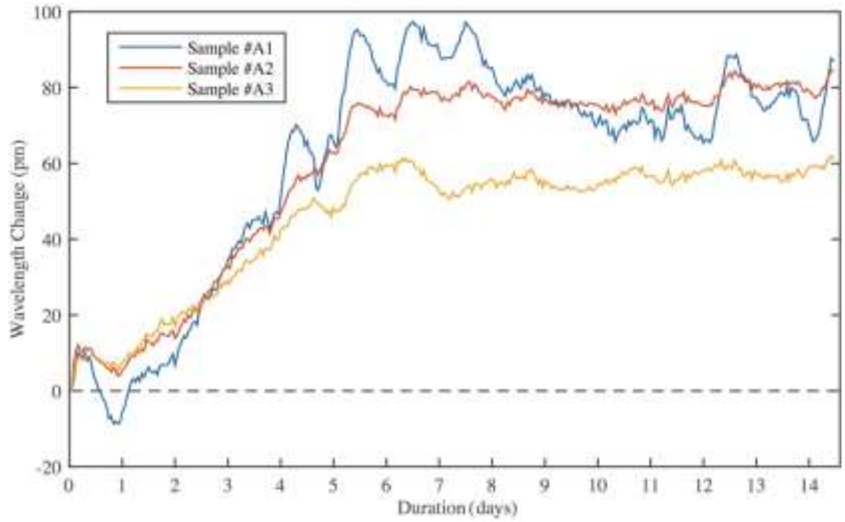


Figure 5. Bragg wavelength changes collected from FBG sensor with *Al-Zn hard coating* after eliminating temperature effect and de-noising.

Table 1. Corrosion rate calculation for tested samples.

Sample number	Initial point for corrosion rate calculation	End point for corrosion rate calculation	Interval between initial point and end point	Corrosion rate
Sample #A1	-8.33 pm (23 hrs)	45.99 pm (86 hrs)	2.63 day	0.14 mil/year
Sample #A2	3.91 pm (22 hrs)	74.71 pm (135 hrs)	4.71 day	0.10 mil/year
Sample #A3	5.10 pm (22 hrs)	48.69 pm (115 hrs)	3.88 day	0.08 mil/year

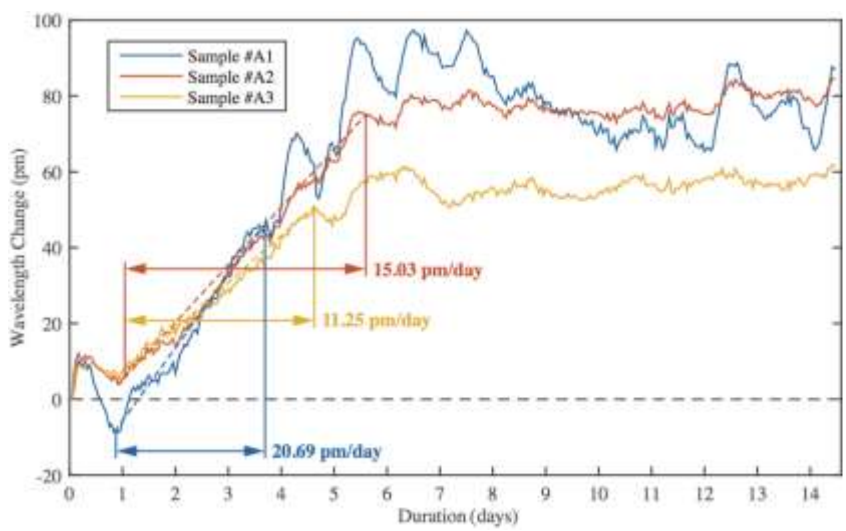
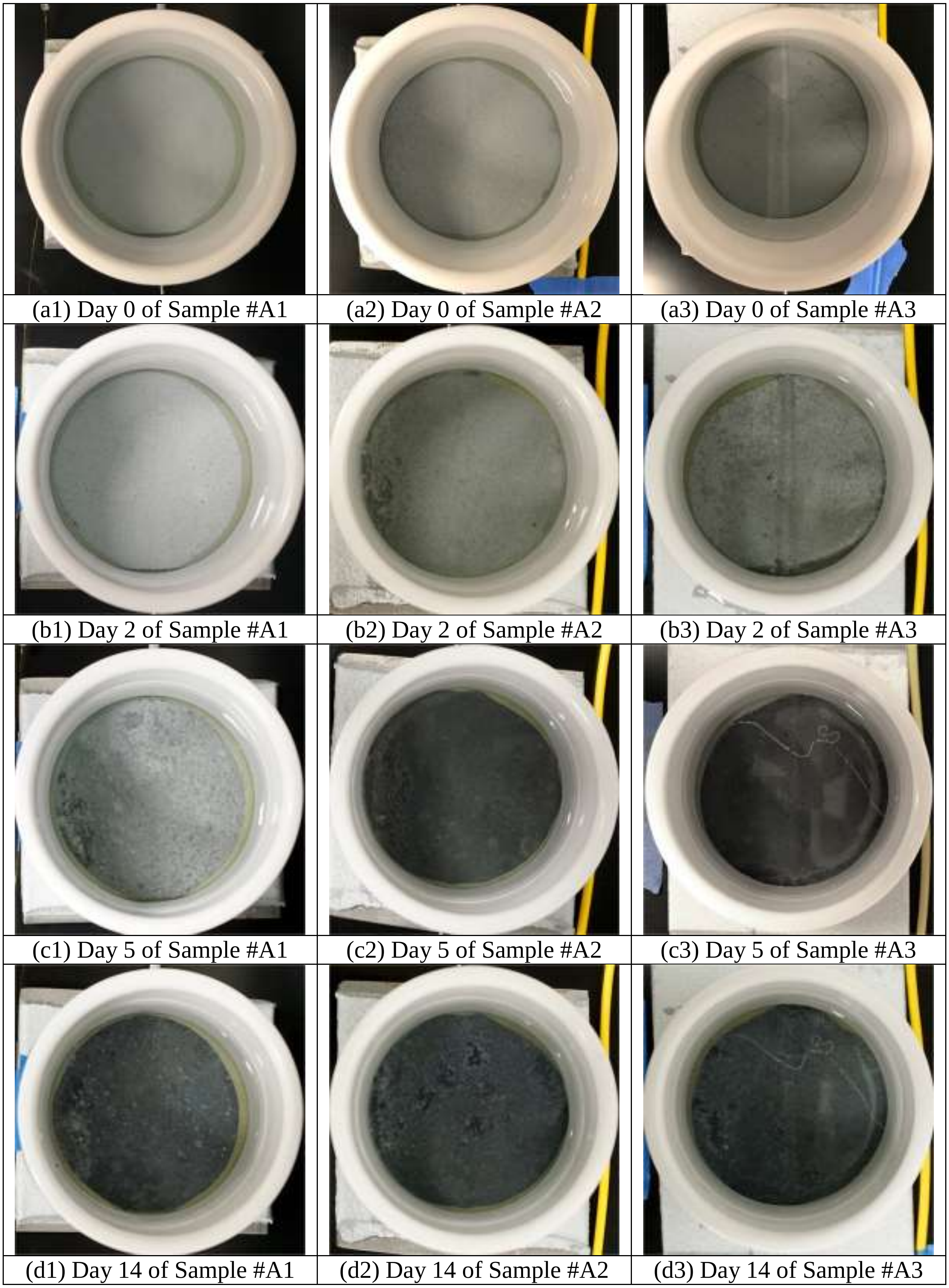


Figure 6. Corrosion rate of three coated samples shown on graph.

Visual inspection results from three tested samples indicated that at Day 2, corrosion started to be found on Sample #A2 and #A3, and at Day 5, more corrosion could be found on all samples.



(a1) Day 0 of Sample #A1 | (a2) Day 0 of Sample #A2 | (a3) Day 0 of Sample #A3

(b1) Day 2 of Sample #A1 | (b2) Day 2 of Sample #A2 | (b3) Day 2 of Sample #A3

(c1) Day 5 of Sample #A1 | (c2) Day 5 of Sample #A2 | (c3) Day 5 of Sample #A3

(d1) Day 14 of Sample #A1 | (d2) Day 14 of Sample #A2 | (d3) Day 14 of Sample #A3

Figure 7. Visual inspection of three samples in accelerated corrosion test.

Taking a close look at the changes of curves in Bragg wavelength of FBG sensors as shown in Figure 6 compared with visual inspection results in Figure 7, reveals that several inner coating cracks could be distinguished by the embedded sensor from Dar 4 as shown in Figure 8. After each crack, the Bragg wavelength of the FBG sensor firstly dropped for a short period, then increased rapidly, suggesting the corrosion rate increased phenomenally, until a new crack was formed and then a new corrosion cycle started. Table 2 showed the corrosion rate of Sample #A1 before each coating crack.

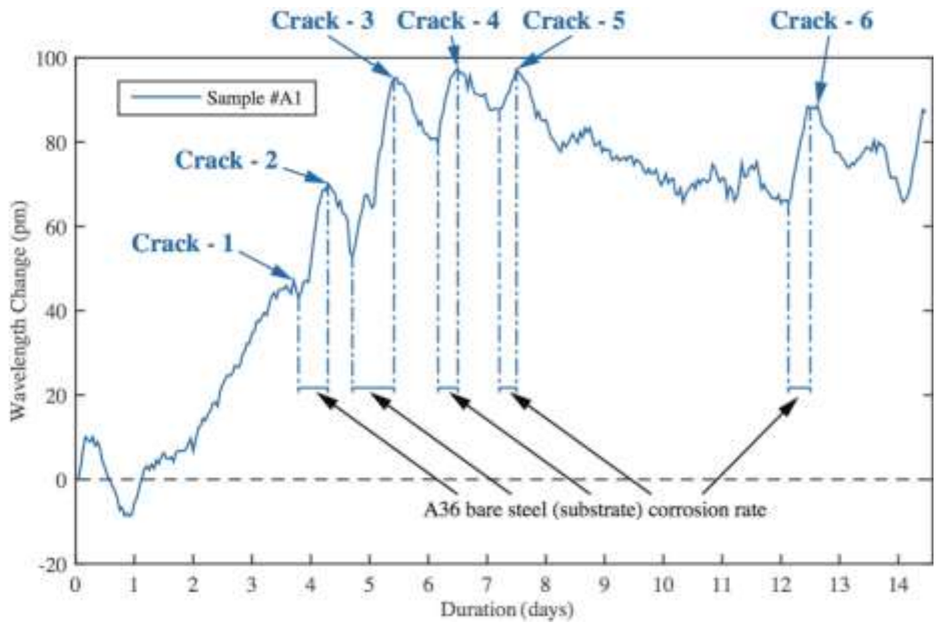


Figure 8. Change of wavelength curves in FBG sensor due to existence of the cracks.

Table 2. Corrosion rate after micro crack formation in hard coating.

Corrosion event	Initial point for corrosion rate calculation	End point for corrosion rate calculation	Interval between initial point and end point	Wavelength Change Slope
Sample #A1 at Crack # 2	44.22 pm (92 hrs)	68.69 pm (101 hrs)	0.38 day	0.44 mil/year
Sample #A1 at Crack #3	52.93 pm (113 hrs)	94.00 pm (129 hrs)	0.67 day	0.42 mil/year
Sample #A1 at Crack # 4	79.76 pm (148 hrs)	97.38 pm (156 hrs)	0.33 day	0.36 mil/year
Sample #A1 at Crack # 5	87.79 pm (173 hrs)	97.25 pm (180 hrs)	0.29 day	0.22 mil/year
Sample #A1 at Crack # 6	65.54 pm (291 hrs)	88.41 pm (299 hrs)	0.33 day	0.47 mil/year

Results from Table 2 indicated that the corrosion rate was drastically increased after formation of cracks in the coating from 0.22 mil/year to 0.47 mil/year. Compared with the initial corrosion rate in Table 1, the fact that Table 2 showed a higher corrosion rate could suggest a combined effect from the coating and its substrate after the occurrence of micro cracks.

From Figure 6 and Table 1, we could find the three tested samples with wire arc Al-Zn hard coating had very consistent performance on accelerated corrosion test. Their calculated corrosion rates were very close (ranging from 0.08 mil/year to 0.14 mil/year with a standard deviation of 0.03 mil/year), which are showing an overall better corrosion resistance compared with the Al-Bronze (Sulzer Diamalloy 1004) hard coating coated by HVOF technique (average: 0.50 mil/year) tested previously.

(c) Description of Problems/Challenges

No problems observed in this quarter.

(d) Planned Activities for the Next Quarter

The planned activities for next quarter are listed as below:

1) Localize corrosion locations on both hard coatings and soft coatings through embedded sensor network (Task 3.2);
2) Sensor networking and corrosion damage characterization (Task 3.2);
3) Risk assessment planning based on the corrosion detection (Task 3.3).