CAAP Annual Report

Date of Report: *09/30/2023*

Prepared for: *U.S. DOT Pipeline and Hazardous Materials Safety Administration*

Annual Period: **From** *(September 30, 2022)* **to** *(September 29, 2023)*

Contract Number: *693JK32250008CAAP*

Project Title: *Performance Evaluation and Risk Assessment of Excessive Cathodic Protection on Vintage Pipeline Coatings*

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Section A: Business and Activities

(a) Contract Activities

- Contract Modifications: NA
- Educational Activities:
  - Student mentoring:

    Yuhan Su, a Ph.D. student in Chemical Engineering at The University of Akron worked on the project starting the 2nd quarter of this project.
  - Student internship: NA
  - Educational activities: NA
  - Career employed: NA
  - Others: NA
- Dissemination of Project Outcomes: NA
- Citations of The Publications: NA
- Others:

  The kick-off meeting of this project was performed on Nov. 14, 2022, with project managers, PIs, and graduate students.

  The project introductory meeting for industrial collaborations was performed on Sept. 20, 2023, with PRCI industrial members, PIs, and graduate students.

(b) Financial Summary

- Federal Cost Activities:
  - PI/Co-PIs/students involvement:

    One graduate student from The University of Akron was partially charged from this project for the salary during this reporting period.

    The PI and Co-PIs had spent time working on the project, but they were charged through cost-sharing not from this project during this reporting period. Because the paperwork for subcontracts just started in the 4th quarter of this project due to short hands in the Research Office at The University of Akron.
  - Materials purchased/travel/contractual (consultants/subcontractors):

Materials were purchased to start experimental setups at The University of Akron during this reporting period.

- Cost Share Activities:
    - Cost share contribution: NA

(c) Project Schedule Update

- Project Schedule:

The proposed research tasks and milestones are shown in Table 1. Task 1 and Task 2 are on the schedule. But Task 1 needs more time to complete because we seek for industrial inputs.

Table 1. Schedule and milestones of proposed tasks.

Tasks	Year 1				Year 2				Year 3			
Task 1. Coating & influencing factors identification	■	■	■									
Task 2. Coating performance evaluation			■	■	■	■	■	■	■	■		
Task 3. Simulation of coating disbondment & CP					■	■	■	■	■	■	■	■
Task 4. Probabilistic coating degradation model					■	■	■	■	■	■		
Task 5. Recoating time determination									■	■	■	■
Task 6. Industrial collaborations	■				■				■			■

- Corrective Actions:

The updated research tasks and milestones are shown in Table 2. The orange ones are updated, and the blue ones remain the same.

Table 2. Updated schedule and milestones of proposed tasks.

Tasks	Year 1				Year 2				Year 3			
Task 1. Coating & influencing factors identification	■	■	■	■	■	■	■	■				
Task 2. Coating performance evaluation			■	■	■	■	■	■	■	■		
Task 3. Simulation of coating disbondment & CP					■	■	■	■	■	■	■	■
Task 4. Probabilistic coating degradation model					■	■	■	■	■	■		
Task 5. Recoating time determination									■	■	■	■
Task 6. Industrial collaborations	■				■				■			■

(d) Status Update of the 4th Quarter Technical Activities

- Task 1: Identification of vintage pipeline coatings and influencing factors in coating cathodic disbondment (The University of Akron and Marquette University)

Task 1 is in progress this quarter. The Ph.D. student, Yuhan Su, at The University of Akron, is working on literature reviews to understand pipeline coatings and the influencing factors in coating cathodic disbondment. The second and third objective of Task 1 are achieving to understand the coating types and influencing factors. In the meanwhile, we sent a survey to PRCI members who are interested in this project to provide us field information for coatings, CP, and etc.

- Task 2: Evaluation of coating cathodic disbondment considering key influencing factors through laboratory testing (The University of Akron)

  The Ph.D. student, Yuhan Su, at The University of Akron, is working on this task. As one CP-compatible coating and one CP shielding coating was determined to be tested, the student is contacting coating suppliers for the purchase. She is also studying the coating characterization methods for cathodic disbondment for experimental design.

- Task 3: Numerical simulation of pipeline coating disbondment behavior and CP system (Rutgers University)

  Task 3 will start in the 5th quarter of this project.

- Task 4: Probabilistic degradation model of coated pipe wall due to excessive CP (Marquette University)

  Task 4 will start in the 5th quarter of this project.

- Task 5: Determination of recoating time using reliability-based approach (Marquette University)

  Task 5 will start in the 9th quarter of this project.

- Task 6: Industrial collaborations (UAkron, Marquette, Rutgers)

  We contacted some oil and gas pipeline companies in the 4th quarter. PRCI is very interested in this project. They invited their members to participate in this project. We had a "kick-off" meeting to introduce this project and present the scope and proposed tasks. Over 20 people from different companies attended the meeting, asked many questions, and provided us with helpful suggestions and comments.

<u>Section B: Detailed Technical Results in the Report Period</u>

1. Task 1. Identification of Vintage Pipeline Coatings and Influencing Factors in Coating Cathodic Disbondment

1.1. Background and Objectives in the 1st Annual Report Period

Buried pipelines are protected from corrosion attack by coating and cathodic protection (CP). However, excessive CP could cause serious damage to many types of vintage pipeline coatings, and consequently pipeline integrity.

The objective of Task 1 in this reporting period is to classify pipeline coatings based on the CP compatibility, that is, to understand which type of the coating belongs to CP-shielding coating and which belongs to CP-compatible coating, and the interaction of each coating with CP (the ability to withstand the alkaline environment created by the CP).

1.2. Research Progress in the 1st Annual Report Period

The coatings used in pipeline include coal tar coatings (coal tar enamel and coal tar epoxy coating), asphalt based coatings (asphalt mastic and asphalt enamel), polyethylene (PE) coatings (PE tape, dual-layer PE, three-layer PE, multi-component PE), fusion-bonded epoxy (FBE) coatings (single-layer FBE, dual-layer FBE, three-layer FBE), three or multi-layer polyolefin polyethylene or polypropylene coatings, high-performance composite coatings (HPCC), etc. [1-3]. Early pipeline coatings like coal tar and asphalt are no longer used to coat newly constructed pipelines due to generally poor field experiences and health hazards. Solid film-backed PE tape is also declining in use because of its poor adhesion, soil stress issues, and external corrosion occurrence. On the other hand, FBE coating is presently the dominant anti-corrosion coating that has been applied to most pipelines in North America [3, 4].

Table 3 summarizes the coatings used in the previous studies. It is evident that FBE coatings were the most frequently studied, followed by PE tape coatings. According to the findings, FBE coatings are regarded as CP-compatible coatings, while PE coatings are considered CP-shielding coatings.

When coating is disbonded at small faults, such as pinholes or holidays, the CP current may be partially or completely shielded, to reach the disbonding crevice, especially at the crevice bottom. As a result, the CP fails to protect the area that is exposed to a corrosive environment. This is called “CP shielding” [5]. Conversely, coatings that do not prevent the distribution of CP current to the steel, are called CP-compatible or CP non-shielding coatings. Generally, widely used coatings like FBE and coal tar enamel coatings are considered CP-compatible coatings, while high-performance coating and PE tape are regarded as CP-shielding coating in the long term.

Table 3. Coatings studies in previous works.

Coating	**Reference**
Coal tar enamel	[6],[7]
Olin Epoxy	[8]
FBE	[5, 9-14]
PE tape	[5, 13, 15, 16]
Disbonded coating	[17]
PU	[18]
Epoxy coating	[19-21]
zirconium-pretreated/epoxy-coating	[22]
Viscoelastic materials	[23]
Chromium metal-oxide-carbide coatings	[24]

The steel metals examined in cathodic disbondment studies were API 5L X series steels, which are commonly utilized as pipeline steel in the field. Table 4 presents the specific models of metals utilized in previous cathodic disbondment investigations.

Table 4. Metals used in cathodic disbondment studies.

Metal	**Reference**
API 5L X52	[6, 8, 9]
API 5L X65	[5, 10, 14, 15]
API 5L X70	[17]
API 5L X100	[16]
Carbon steel panel (SAE 1020)	[18]
L360 QS steel	[19, 20]
St14 steel panels	[22]

1.3. Company Survey

A survey was sent to industrial companies who were interested in this project through the network of PRCI. The survey aims to obtain field information from pipeline industry partners. The survey questions are listed below:

1. Please provide your company name

2. Please list out the coating type(s) that have been used in the vintage pipelines (that could be over 30 years old)?

3. Please list out the coating type(s) that have been used within recent 20 years?

4. Has your pipeline experienced coating cathodic disbondment issues?

Please provide addition information regarding the cathodic disbandment incident.

5. What type of coating is it where the cathodic disbandment incident occurs?

6. What is the type product transported by the pipeline?

Gas; Oil; Others

7. Year of pipeline installation

8. Was the pipeline subjected to any interference from foreign objects?

No; Yes, power lines; Yes, railroads; Yes, pipeline crossing

9. Was this pipeline cathodic protected?

No; Yes

10. What type of cathodic protection is used? And what is the design voltage or current?

Sacrificial anode, with the following design voltage or current;

Impressed current, with the following design voltage or current

11. Any other information that you would like to add for this cathodic disbondment incident?

1.4. Conclusions

Through the literature reviews, the types of pipeline coatings and the associated metals have been understood.

1.5. Future Work

The influencing factors in coating cathodic disbondment will be reviewed and summarized in the next reporting period. It is expected to obtain some useful information from the industrial survey.

2. Task 2. Evaluation of Coating Cathodic Disbondment Considering Key Influencing Factors through Laboratory Testing

2.1. Background and Objectives in the 1st Annual Report Period

A systemically coating performance evaluation will be designed and conducted through experimental testing to study coating cathodic disbondment considering key influencing factors.

The objective of Task 2 in this reporting period is to understand characterization methods used in coating cathodic disbondment and to obtain the detailed information of coatings that were studied for cathodic disbondment in literature.

2.2. Research Progress in the 1st Annual Report Period

Figure 1 summarizes the ex-situ and in-situ cathodic disbondment (CD) assessment to mitigate CD and related corrosion. Ex-situ CD tests, comprising standard CD tests and modified CD tests, serve as valuable references for selecting suitable coatings for field application. In the meanwhile, in-situ CD tests, such as Electrochemical Impedance Spectroscopy (EIS), Localized Electrochemical Impedance Spectroscopy (LEIS), Scanning Kelvin Probe (SKP), Scanning Vibrating Electrode Technique (SVET), Scanning Acoustic Microscopy (SAM), and Wire Beam Electrode (WBE), aid in monitoring the disbondment behavior of coatings in real-world conditions and facilitate timely adjustments of CP levels.

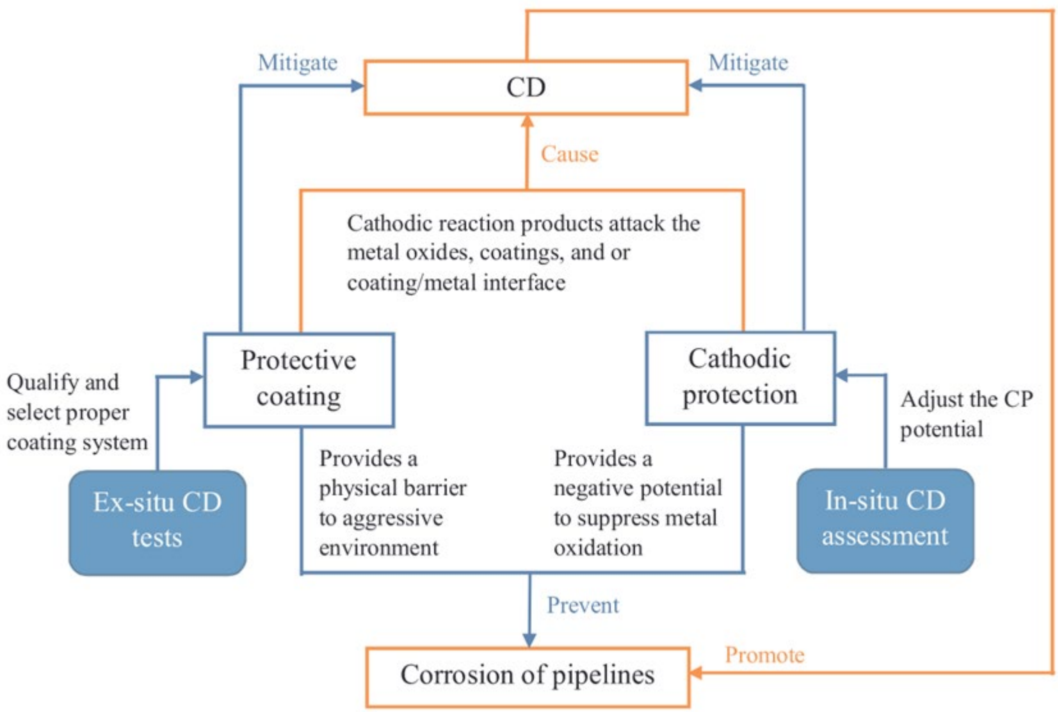

Figure 1. Ex-situ CD and in-situ CD assessments to mitigate CD and related corrosion of coated pipelines.

Table 5 presents a comprehensive overview of the ex-situ and in-situ characterization methods utilized, along with the cathodic disbondment standards employed in the literature. It is evident that the ex-situ CD test is the most applied method for investigating cathodic disbondment, followed by in-situ tests. Additionally, researchers have conducted CP permeability tests on coatings to assess their ability to shield CP current and examine the influence of CP shielding on the coating cathodic disbondment. The local pH test is employed to monitor the alkalinity of the holiday, offering valuable insights into its corrosion behavior. Table 6 shows the details of FBE coatings used in previous studies. The thickness of FBE coatings ranges from about 120 μm to about 500 μm. Table 7 includes the CP potentials adopted in CD testing. Also, the applied CP potentials vary very much among these published works.

Table 5. Characterization methods and CD standards used in previous studies.

Characterization	CD Standard	Reference
CD test	CSA Z245-20	[8, 13, 14, 18-20, 23, 24]
	CSA Z245-21	
	ASTM G8	
	ASTM G95	
CP permeability		[5, 6]
pH test		[5, 6, 17]
Water permeability		[9, 13]
EIS		[9, 11-13, 18-20, 22, 23]
SEM		[9, 16]
WBE		[19-21]
SKP		[10, 24]
PCCP		[19]
SWP		[16]

PCCP – pulsed current cathodic protection
SKP -- Scanning Kelvin Probe
SWP -- Square-wave polarization

Table 6. FBE coating thickness used in previous studies.

FBE coating thickness/μm	Reference	Notes
180	[9]	membrane
250	[5]	membrane
180	[10]	
381-508	[13]	Standard thickness
127		Thin thickness
280, 450	[25]	Powder coating 3MT ScotchkoteT Fusion-Bonded Epoxy 6233P

Table 7. CP conditions used in previous coating cathodic protection studies.

CP Conditions	Reference	Notes
-1.3 V vs SCE	[19]	Pulse current + direct current
-1.4 V vs SCE		
-1.5 V vs SCE		
-1.5 V	[8]	Canada Z245-20-10; not mention the RE
-0.875 V vs SCE	[14]	AC current density (0-500)
-1.5 V vs SCE	[18]	ASTM G8
-0.9~-1.5 V vs SCE	[20]	
-1.5 V vs SCE	[13]	ASTM G95
-1.38 +- 0.02 V vs Ag/AgCl	NACE TM0115	-1.399 V vs SCE
-1.45~1.55 V vs CSE	ASTM G8	-1.373~-1.473 V vs SCE
-3 V vs CSE	ASTM G95	-2.923 V vs SCE

2.3. Conclusions

The characterization methods for coating cathodic disbondment have been understood. The FBE coating and applied CP potentials in previous studies for cathodic disbondment have been summarized.

2.4. Future Work

An experimental design for investigating coating cathodic disbondment will be undertaken. Lab prepared coating samples or commercially purchased coating samples will be ready for testing.

3. Task 3. Numerical Simulation of Pipeline Coating Disbondment Behavior and CP System

Task 3 will start in the 5th quarter of this project.

4. Task 4. Probabilistic Degradation Model of Coated Pipe Wall Due to Excessive CP

Task 4 will start in the 5th quarter of this project.

5. Task 5. Determination of Recoating Time Using Reliability-based Approach

Task 5 will start in the 9th quarter of this project.

6. Task 6. Industrial Collaborations

The PIs contacted external partners from the oil and gas pipeline industry for industrial collaborations during this reporting period. PRCI demonstrated their interest in this project. They invited their members to participate in it and generated a platform to share project information on their website. We had a “kick-off” meeting with them to introduce the project and present the score and tasks of this project. Over 20 people from different oil and gas companies attended the meeting, asked many questions, and provided us with helpful suggestions and comments. We sent a survey to these attendants to acquire field information. We also mentioned the needed sources if these companies can provide including vintage coating samples and commercially available new coating samples. We will update PRCI and their members on our project progress and outcomes in the next reporting period.

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