CAAP Quarterly Report

Date of Report: January 28, 2020

Contract Number: 693JK31950003CAAP

Prepared for: Government Agency: DOT

Project Title: Fundamental Understanding of Pipeline Material Degradation under Interactive Threats of Dents and Corrosion

Prepared by: Iowa State University

Contact Information: Professor Ashraf Bastawros,
T.A.Wilson Professor of Engineering,
Department of Aerospace Engineering
2271 Howe Hall, Rm 1200
Ames, IA 50011-2271
Phone: 515-294-3039 Fax: 515-294-3262
Email: bastaw@iastate.edu

For quarterly period ending: December 31, 2019

Business and Activity Section

(a) Generated Commitments – New teaming arrangement is being negotiated to include Prof. Kurt Hebert from the Chemical Engineering department at Iowa State University to bring a coherent modeling electrochemical impedance spectroscopy experimental work. No additional funding or commitments will be requested from the CAAP program.

(b) Status Update of Past Quarter Activities - The main objective of the proposed work is to enrich the knowledge base for evaluating interactive threats of external mechanical dents and secondary features, through and integrated lab-scale experimental and numerical framework to characterize and better predict the remaining safe life and operating pressures, while projecting the needs for mitigation measures.

The proposed experimental-computational framework will address the interacting threats of external mechanical damage, coupled with secondary feature as corrosion or cracking on the integrity management decision. The proposed methodologies utilize: (i) A high throughput lab-scale testing apparatus for simulating the combined threats of external damage induced plastic deformation combined with exposure to corrosion, (ii) A lab-scale experiments to assess the synergistic interaction between different threats and their effects on strength and toughness of corrosion degraded pipeline steel, (iii) Utilization of electrochemical impedance spectroscopy (EIS) as a path way for ILI-implementation to characterize the severity of the corrosion near an external mechanical damage, (iv) A detailed FEM analysis of the different geometric constraints

on the variance of local stress and strain state (concentration), and (v) Systematic numerical sensitivity analysis in FEM to quantify metrics for material strength and toughness degradation with corrosion and under the interacting threats of external mechanical damage, and stochastic interpretation of the variation in reported full scale fatigue testing of dents (PRCI MD 4-2, 4-9).

The Major activity during this period involved a kick-off meeting and planning experimental and numerical protocol, focusing on sample preparation and synergistic testing.

1. We held a keck-off meeting on Nov. 13, 2019 via WebEx and attended by the PIs, graduate students and the program monitor. The project objectives, milestones and deliverables have been presented and discussed.
2. We communicated with Mark Piazza from Colonial Pipeline to act as our industrial advisor and review our project planning and targeted milestones.
3. We have acquired a set of pipeline samples of different steel grades. The major work will continue to be on high strength X70 Steel Pipes.
4. We have setup the sample preparation and testing protocol for the simulation of combined threat testing.
5. A graduate student and an undergraduate minority student are involved in the work.

(c) Details of the Tasks:

Task 1- High Throughput Lab-Scale Interactive Threat Screening Apparatus (Month 1-3)

This task has been completed, with full design and implementation of the in situ stress application during the electrochemical corrosion as shown in Fig. 1. The corrosion setup has a micro-cell and loading mechanism. The new setup will be used to mimic the interactive role of applied stress (resulting from local gauge or indents) on the IGSCC conditions with variable time and stress levels. Figure 1 shows the current version of the new setup. The setup consists of (1) the micro-cell, (2) the sample holder mounted on the horizontal rail, (3) the vertical linear translation stage with the micrometer adjustment and load transducer. In order to maintain a better contact between the micro-cell and the samples, a silicone rubber cap is attached at the bottom orifice of the micro-cell. The rubber cab can also provide variable corrosion area by altering the hole diameter. The experimental protocol includes (a) the cantilever X70 steel strip is mounted in the sample holder, (b) the sample is loaded at its free-end by the vertical translation stage (the level of deflection is adjusted by the desired bending stress level that is required at the root of the beam), (c) the micro-cell is engaged with the sample surface near by the root of the cantilevered sample, (d) the micro-cell is filled with the electrolyte and the corrosion experiment is carried out under the constant deflection, while the corresponding end-load is monitored by the load transducer attached to the vertical stage.

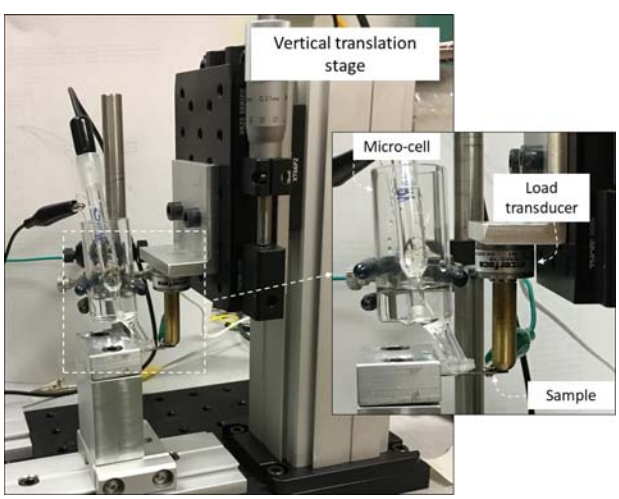

Fig. 1: The micro-cell corrosion setup with the loading mechanism to mimic IGSCC conditions with variable stress levels.

Summary of preliminary tests, summarized on Fig. 2 show that if the pipeline material (API X70 in this case, exposed to bicarbonate solution with 8.5pH) is subjected to concurrent stress below 0.85 SMYS and electrochemical corrosion, the surface exhibited corrosion characteristics similar to that of an unloaded sample, by forming a conforming oxide layer that diminishes the electrochemical dissolution current quickly, and does not result is sever GB grooving. However, when the sample is loaded to 1.15 SMYS, either concurrently, or unloaded then exposed to electrochemical corrosion, sever GB grooving were observed with sustained corrosion current for extended period (up to 10hrs compared to 1hr for unstressed sample). The topological inserts on Fig. 2(a) show a through thickness cross-section highlighting the significant GB grooving, which would act as a cracking nucleus to accelerate the fatigue failure. Uniaxial tensile tests on the corroded samples after 24hrs, shown in Fig. 2(b), showed about 12% reduction in SMYS and about 25% reduction in toughness (measured from the area under the curve).

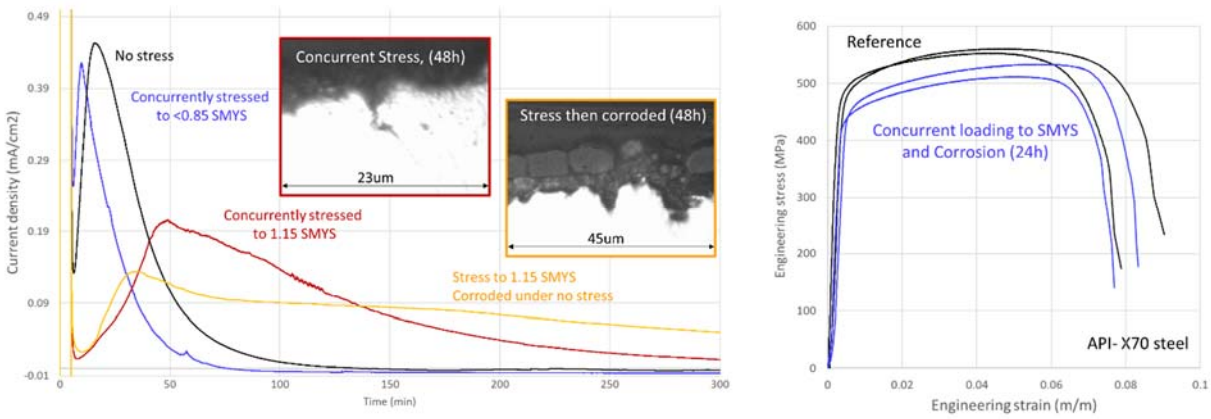

Fig. 2: Preliminary investigation on interactive threats of mechanical dent induced residual plastic deformation and the accelerated corrosion. Samples subjected to residual stress level in excess of SMYS showed significant corrosion, GB grooving and reduction in both strength and ductility.

Outcome: All sample preparation procedure and corrosion testing protocol are in place. Several exploratory experiments have been conducted to show the relative role of the applied stress on the evolution of the corrosion state. The preliminary results highlight the role of over-stressing by external mechanical damage (dent or gouge), wherein the threshold stress for crack initiation may be below the mean operating stress.

(d) Planned Activities for the Next Quarter – The focus of the next phase of work will be on the lab-scale investigation of dent-corrosion interactive threats. In particular we will conduct:

1. Preloading of set of samples to various plastic strains ranging between 0.5 to 5%.
2. Perform electrochemical corrosion experiments on these samples and observe the subtle changes in the current-voltage characteristics as well as the corrosion morphology
3. Perform a tensile stress test to failure to characterize the remaining strength of the samples.

These measurements would provide some of the material parameters for the numerical framework.