CAAP Quarterly Report

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

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Business and Activity Section

(a) Generated Commitments – The research team has done its best to progress, despite the sever constraints imposed by the COVID-19 pandemic. To remedy these hurdles, we are changing the order of the tasks to maintain our progress. A request of no cost extension will be requested from the CAAP program to carry out all conducted tasks.

(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 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).

To remedy the constraints imposed by the pandemic, we have changed the order of the tasks and now we are working on tasks 2 and 4 concurrently. The main activity during this period focused on simulation framework and accelerated corrosion testing.

1. Task-4: Developed of the simulation framework within Abaqus finite element simulation package to simulate the combined threat of dents and corrosion on the fatigue life response of pipelines.
2. Task-2: Development of miniaturized tensile test configuration for accelerated chemomechanical testing.

(c) Details of the Tasks:

C.1 Task 4- Experimentally calibrated numerical framework (Month12-36)

A finite element analysis (FEA) is conducted for investigating the effect of plain dents on the fatigue life of pipelines. This activity starts by creating the geometric model of the pipe, which has an outer diameter of 50 mm and total length of 200 mm. The pipe is then discretized to linear quadrilateral thin shell elements ignoring the variation of stress in the direction of pipe's thickness. To simulate the actual boundary conditions of buried pipelines, all displacement components are prevented at the lower part of the pipe, while both sides of the pipe are left free.

Furthermore, a spherical rigid indenter is used to simulate the indentation process. After indentation, two cycles of an internal pressure are applied to the internal face of the pipe. The FEM analysis uses an elastic–plastic simulation scheme of the indentation as well as the cyclic pressure loading. The loading sequence is started by moving the indenter in the vertical direction with a velocity of -0.1 mm/s. After reaching an indentation depth of 4.0 mm, the indenter is forced to move upward with a velocity of 0.1 mm/s enabling the material to recover all elastic strains. After imposing residual stress in the pipe, two cycles of internal pressure are applied to simulate the fluctuating load on the pipe.

Figures 1 and 2 present the distribution of Von-Mises stress during loading and unloading indentation processes. During the loading part, a slight ovality is observed in the pipe as it can be indicated form the concentration of stress along the longitudinal direction of the pipe as shown in Figure 1. After removing the indenter, the pipe recovers all elastic strains, as shown in Figure 2.

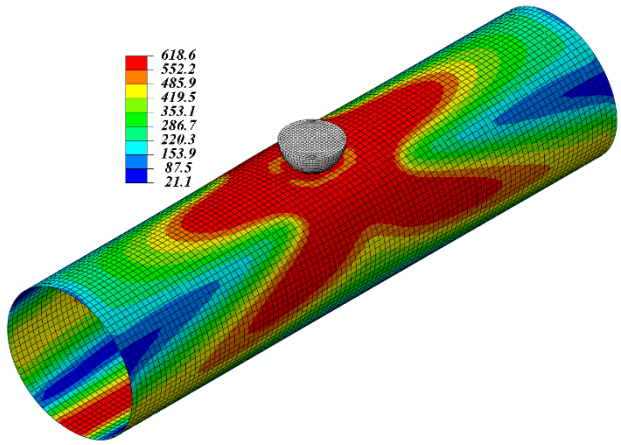

Figure 1: Contours of Von-Mises stress (MPa) during the loading stage of the indentation process

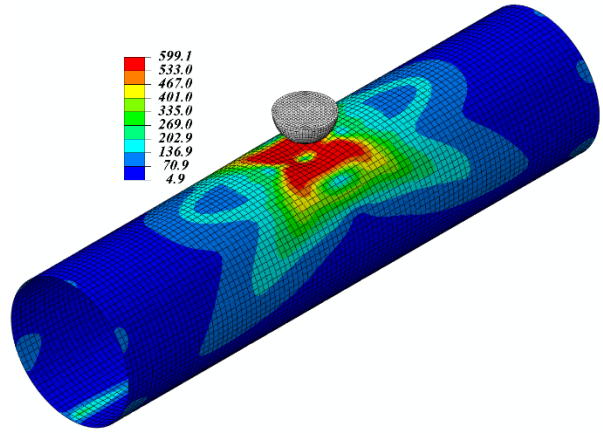

Figure 2: Contours of Von-Mises stress (MPa) during the unloading stage of the indentation process

After imposing residual stress in the pipe through a spherical dent, two cycles of internal pressure with a magnitude of 3.5 MPa are applied to simulate the fluctuating load, as shown in Figure 3. Figures 4 illustrates the distribution of Von-Mises stress after applying an internal fluctuating pressure. As it can be seen some damage are accumulated at points of maximum stress, which is approximately at 45 degrees from the longitudinal direction of the pipe.

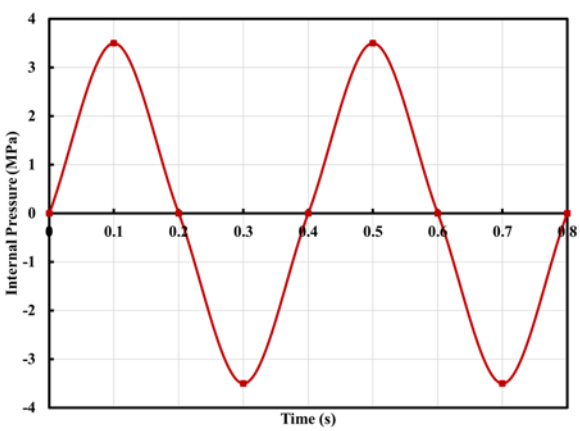

Figure 3: The variation of the applied internal pressure with respect to the simulation time

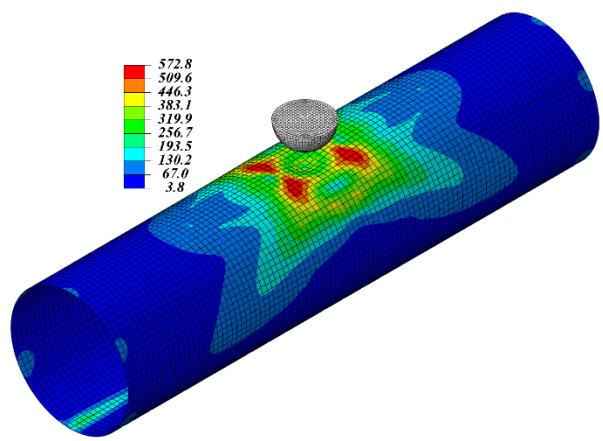

Figure 4: Contours of Von-Mises stress (MPa) after two cycles of internal pressure.

To further analyze the effect of fluctuating load on the fatigue life of dented pipes, the variation of equivalent plastic strain as well as the Von-Mises stress with the indentation depth are plotted and presented in Figures 5 and 6, respectively. The accumulation of the damage due to the applied load can obviously observed in Figure 6.

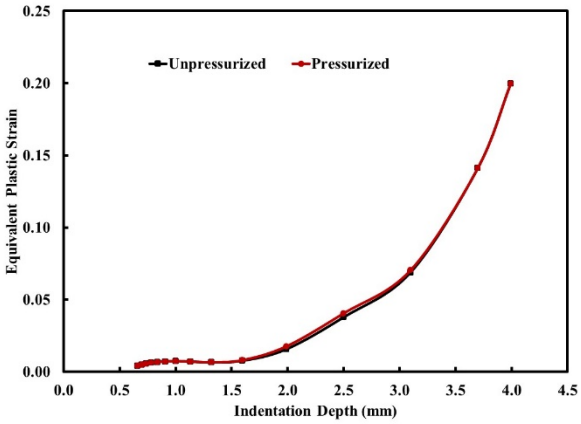

Figure 5: The variation of the equivalent plastic strain with respect to the indentation depth for pressurized and unpressurized pipes.

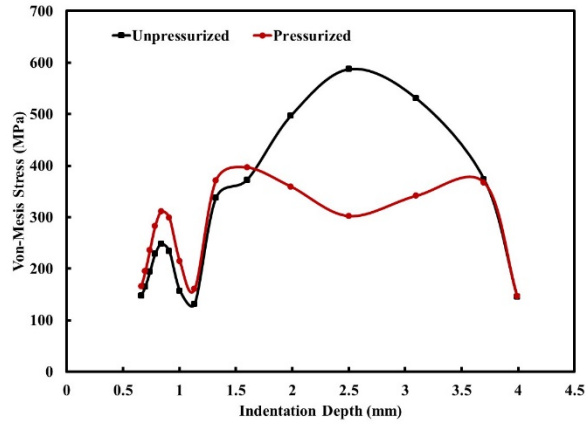

Figure 6: The variation of the Von-Mises stress with respect to the indentation depth for pressurized and unpressurized pipes.

Future direction: In the next reporting period, this task will be continued by constructing the S-N curves for the pipe before and after the application of fluctuating pressure. Furthermore, the effect of corrosion on the mechanical behavior of the tested material will be taken into consideration. In this way, the fatigue life of an operating pipe with a plain dented subjected to corrosion will be accurately assessed.

C.2 Task 2- Lab-scale investigation of dent-corrosion interactive threats (Month1-18)
The effect of scaling down on stress distribution of testing samples

For the experimental work, we focused on the development of miniaturized testing sample to accelerate the experimental investigation of the chemo-mechanical interactive threats. We focused on the effect of sample scaling on the consistency of the measured mechanical properties of the tensile samples. A detailed finite element comparative study is conducted to assess all these geometric effects. This activity starts by creating the geometric models of the tested samples. Two models are created. The first sample is constructed according to the ASTM E8/E8M standard, which has a total length of 100 mm and thickness of 1.0 mm. In addition, the first model has been scaled down by 0.1 scaling factor resulting in a miniaturing sample. Taking the advantage of symmetry towards saving the computation time, only one quarter of each model is used. The lower and left sides of each sample are set as symmetric boundary conditions in the vertical and the horizontal directions, respectively. Mesh grid is generated using linear quadrilateral three-dimensional elements. Displacement boundary condition is applied at the right edge of the sample to simulate the tensile loading.

As shown in figures 7 and 8 the distribution of stress along the tested sample is almost identical for both scaled and unscaled samples. This is also confirmed in the stress-strain relation presented in figure 9. In this way, miniature samples can be used in corrosion experiments, which will save the limited samples of the X70 steel that we have.

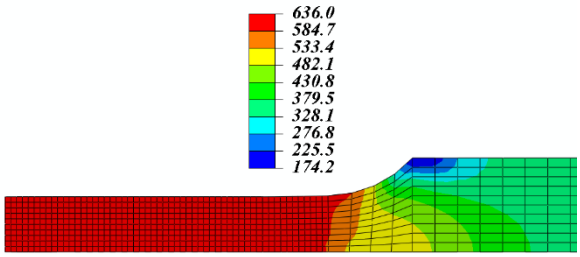

Figure 7: Contours of Von-Mises stress (MPa) for the full-scale sample

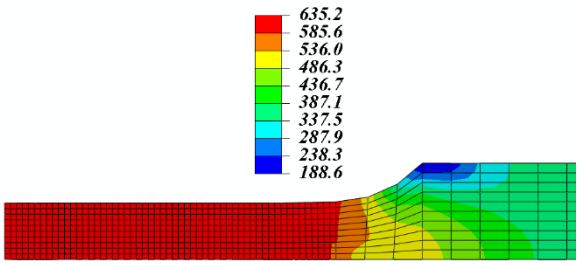

Figure 8: Contours of Von-Mises stress (MPa) for the scaled sample

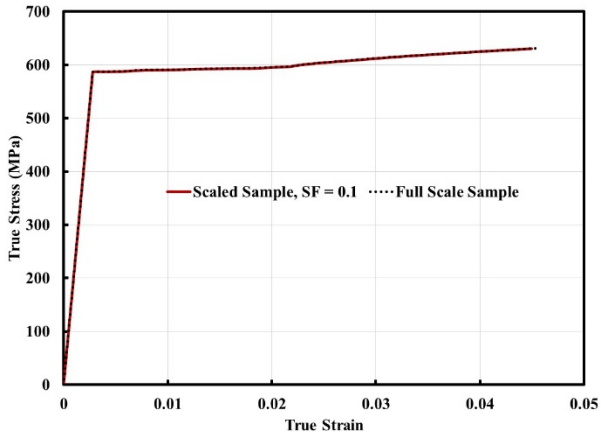

Figure 9: True stress-true strain relation for scaled and unscaled samples