CAAP Quarterly Report

01/05/2025

Project Name: Development of Compatibility Assessment Model for Existing Pipelines for Handling Hydrogen-Containing Natural Gas

Contract Number: 693JK32250004CAAP

Prime University: University of Oklahoma

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Reporting Period: 09/30/2024 – 12/29/2024

Project Activities for Reporting Period:

The project team has consistently maintained a comprehensive master database to ensure it reflects the most up-to-date hydrogen embrittlement (HE) data for carbon steels used in pipeline applications (Task 1.4). Regular data cleaning processes are conducted to address inaccuracies and inconsistencies, enhancing the reliability of the database. Incorporating the experimental data generated through this project (area reduction, fracture toughness, and fatigue propagation rate), advanced machine-learning models have been developed and implemented in a computational tool to accurately predict the reduction of area and fracture toughness of pipeline steels.

The team conducted laboratory experiments to evaluate the impact of hydrogen embrittlement (HE) on the fatigue behavior of pipeline steel (Task 2.4). This involved preparing pre-cracked compact tension (CT) specimens and subjecting them to fluctuating loads to determine the fracture propagation rate. Before the main fatigue tests, cyclic loading under atmospheric conditions was applied to the specimens to simulate natural fatigue crack formation. Subsequently, the primary fatigue experiments were performed in a hydrogen-rich environment to assess the influence of hydrogen on crack growth rate and material degradation under operational conditions. Completion of this task is anticipated by the end of the next quarter.

During this reporting period, the team also enhanced the Compatibility Assessment Model, which evaluates the suitability of pipeline materials for hydrogen transport by analyzing fatigue crack growth. The model's primary output, fatigue crack growth rate predictions, is used to estimate the pipeline's life expectancy under hydrogen service, considering cyclic loading conditions. Cyclic loading significantly accelerates crack growth in the presence of hydrogen, necessitating robust assessment of the pipeline's resilience to repeated pressure fluctuations. By simulating crack growth over multiple load cycles, the model estimates the pipeline's operational life and the allowable number of cycles before failure occurs.

To facilitate pipeline integrity analysis, a sensitivity analysis model developed previously has been refined. This model identifies critical parameters affecting fatigue crack growth and assesses their influence on material performance. The sensitivity analysis begins with baseline input values, followed by systematic variation of individual parameters while holding others constant. The impact of each parameter is quantified by comparing the changes in the model's output against the variations in the input.

Additionally, the research team developed a computational tool with input and output validation capabilities (Tasks 5.1 and 5.2) and a Graphical User Interface (Task 5.3). The initial version of the tool has undergone extensive testing to ensure accuracy and reliability. The input validation module safeguards against invalid inputs and ensures that predictions remain accurate by restricting input ranges to physically meaningful values. An authentication system alerts users to invalid inputs and specifies acceptable ranges. The output validation module employs algorithms to predict output ranges under extreme conditions, reducing the risk of generating uncertain or erratic predictions. The tool also displays intermediate calculations and results, facilitating problem identification during analysis.

The Graphical User Interface, designed for user-friendly interaction, features separate windows for input, analysis, and results visualization. It guides users through entering inputs, indicating their descriptions, units, and acceptable ranges. In the analysis window, users can select the type of analysis, such as compatibility or sensitivity assessments, and provide relevant parameters. Results are displayed in multiple formats, including tables and plots, enabling easier interpretation and decision-making.

Project Financial Activities Incurred during the Reporting Period:

Table 1 presents expenses during the reporting period in each budget category.

Table 1: Quarterly expense breakdown

Budget Category	DOT-PHMSA	OU Cost Share	Total
Salary & Wages	$ 30,572	$14,815	$45,387
Fringe Benefits	$ 2,975	$4,563	$7,538
Supplies	$ 2,473	$0	$2,473
Travel - Domestic	$ 2,315	$0	$2,315
Other	$ 140	$0	$140
Equipment	$ 3,379	$0	$3,379
Tuition	$ 13,566	$0	$13,566
IDC	$ 23,729	$10,658	$34,387
Total	**$ 79,150**	**$30,037**	**$109,187**

Note: Actual expenses may differ slightly from those presented in this table.

Project Activities with Cost Share Partners:

The Principal Investigator (PI) and co-PI participated in various research and development activities, such as supervising research assistants and technical staff, conducting hydrogen embrittlement research, and operating experimental setups.

Project Activities with External Partners:

Not applicable.

Potential Project Risks: None

Future Project Work:

In the coming months, the project team will concentrate on completing fatigue tests using compact CT specimens to evaluate the effects of various stress intensity factor ranges, load ratios, gas compositions, and temperatures on fatigue crack propagation rates. This study aims to produce robust experimental data to enhance the existing database, which supports the development of a machine-learning model for predicting fatigue crack propagation rates. This predictive model is instrumental in estimating the service life of pipelines subjected to cyclic loading conditions, providing critical insights for guiding modifications to existing infrastructure to ensure the safe transport of hydrogen and hydrogen-containing gases.

Additionally, efforts to refine and advance the computational tool will continue in the next quarter. Planned improvements include enhancements to input and output validation modules and the graphical user interface. Furthermore, a cloud-based system will be implemented to enable remote analysis, eliminating security limitations associated with local systems and providing broader accessibility to users. Built with PyQt5, the tool provides a clean and modern graphical interface for intuitive use. Five main tabs structure the user interaction:

Program Input Tab: Accepts material composition such as Iron, Carbon, and Manganese content and Ultimate Tensile Strength, Pipeline Geometry (material thickness, initial crack depth, and length), and operating conditions such as maximum and minimum pressure and hydrogen concentration.

Program Output Tab: Displays detailed results, including the predicted number of cycles, Predicted area reduction, lifetime in hours, termination conditions, and fatigue data table, which features the Number of Cycles and stress Intensity Factor Range. The simulation results are also downloadable for further analysis.

Plots Tab: Visualizes key relationships such as crack growth rate as a function of stress intensity factor range, Crack depth progression over cycles, and crack depth per time (in hours).

Sensitivity Analysis Tab: Allows users to explore the effect of parameter variations on pipeline performance. Parameters such as hydrogen Concentration, Initial Crack Depth, Initial Crack Length, Ultimate tensile strength, load ratio and so on can be used for performing the sensitivity analysis.

Help Tab: Provides comprehensive guidance on using the software.

Potential Impacts to Pipeline Safety:

Our tool is now capable of predicting the extent of hydrogen embrittlement (HE) that may occur during hydrogen transportation through existing gas pipelines. These predictions enable the identification of a safe operating range for transporting hydrogen within natural gas pipelines, ensuring material integrity and operational safety.