CAAP Quarterly Report

04/03/2025

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: 12/30/2024 – 03/29/2025

Project Activities for Reporting Period:

Periodic maintenance of the database is essential to ensure alignment with the advancing predictive capabilities of the hydrogen embrittlement (HE) assessment tool. As the tool evolves, the master database must expand to incorporate new experimental data generated by this project and other relevant studies. Accordingly, during this reporting period, the project team updated the master database to reflect the most current HE data for carbon steels used in pipeline applications (Task 1.4). Data cleaning was conducted to address observed inaccuracies and inconsistencies, particularly in predicting fatigue crack propagation rates during sensitivity analysis. This process enhances the accuracy of the tool's predictions, resulting in a more consistent and realistic correlation between crack growth rate and stress intensity factor range. Accurate prediction of crack growth rates is essential for assessing the service life of pipelines under various operating conditions.

In addition to database enhancements, the team conducted fatigue cracking experiments to assess the impact of HE on the fatigue behavior of pipeline steel (Task 2.4). The fatigue behavior was evaluated using the fracture mechanics approach in accordance with ASTM E647. Fatigue crack growth rate (da/dN) was plotted as a function of the stress intensity factor range (ΔK) to support the prediction of a component's remaining fatigue life. Compact tension (CT) specimens were initially fatigued and pre-cracked under atmospheric conditions in the air for these tests. Subsequently, the specimens were exposed to a mixture of hydrogen and natural gas within an autoclave and subjected to cyclic loading to determine the crack propagation rate. Multiple fatigue crack propagation experiments were conducted during this reporting period, varying gas composition, material type, load ratio, and stress intensity factor range. This task is scheduled for completion in the next quarter.

A key deliverable of this project is the development of a user-friendly computational tool capable of performing compatibility assessments and sensitivity analyses under various operating conditions, with outputs presented through descriptive graphics to facilitate user interpretation. The initial version of the tool has undergone extensive testing to ensure its accuracy and reliability. During this reporting period, the project team concentrated on validating the tool's performance under a range of field-relevant scenarios and operating conditions (Task 5.2). The validation studies indicated that accurate service life prediction depends on reliable estimation of crack propagation rates at low stress intensity factor ranges ($\Delta K < 5$ MPa$\sqrt{m}$). However, due to the limited availability of experimental data in this low ΔK region, machine learning models produced unrealistic fatigue crack growth rate predictions, leading to inaccurate service life estimations. To address this issue, the experimental database was augmented with additional data points generated through systematic extrapolation of crack growth rate curves, thereby incorporating low ΔK values into the dataset. We will upgrade our ML models based on the improved database.

Furthermore, we worked closely with our IT department to establish a cloud-based platform for executing the computational tool within a virtual environment. The platform will include 50 GB of storage, 16 GB of VM RAM, and two CPUs to support concurrent use by two users. Our team will hold administrative privileges on the server and ensure all necessary configurations are properly implemented. Non-OU users will obtain affiliate status to access the server and utilize the tool. We have also developed a user-friendly, interactive Graphical User Interface (GUI) for the computational tool (Task 5.3). The GUI (**Fig. 1**) features dedicated windows for input entry, analysis execution, and output display. A user guide is included to assist users in entering program inputs by providing descriptions, units, and acceptable ranges. In the analysis window, users can select the desired analysis type, such as compatibility assessment or sensitivity analysis, and input the required parameters. The GUI also enables users to view results in various formats, including tables and plots, to facilitate interpretation.

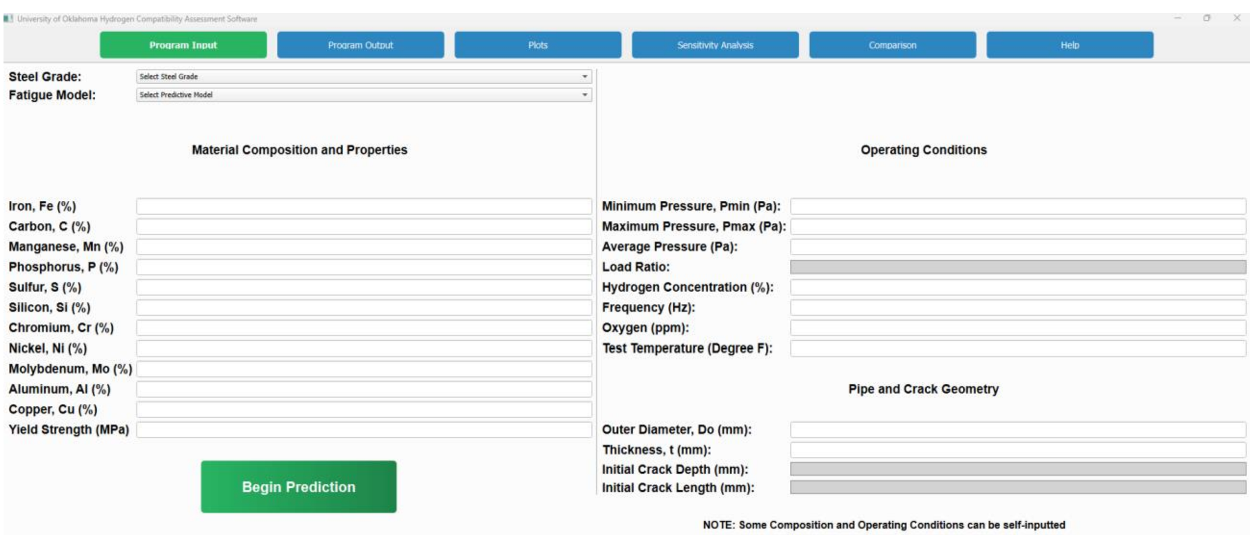

Fig. 1 GUI of the computational tool

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	$26,308	$7,227	$33,535
Fringe Benefits	$2,560	$2,226	$4,786
Supplies	$130	$0	$130
Travel - Domestic	$0	$0	$0
Other	$345	$0	$345
Equipment	$3,546	$0	$3,546
Tuition	$14,652	$0	$14,652
IDC	$16,139	$5,199	$21,338
Total	**$63,680**	**$14,652**	**$78,332**

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

Project Activities with Cost Share Partners:

The Principal Investigator participated in various research and development activities, such as supervising research assistants and technical staff, conducting HE research.

Project Activities with External Partners:

Not applicable.

Potential Project Risks: None

Future Project Work:

In the coming months, the project team will continue fatigue tests using compact CT specimens to evaluate the effects of various factors, including material type, load ratio, gas composition, and temperatures, on fatigue crack propagation rate. The experimental data will enhance the existing database to improve the predictions of a machine-learning model for forecasting fatigue crack propagation rates. The model is critical in determining the service life of pipelines subjected to hydrogen-containing natural gas under cyclic loading conditions.

Additionally, we will continue our efforts to refine the computational tool in the next quarter. Planned improvements include enhancements to output validation modules. Specifically focusing on accurate prediction for field scenarios involving low-stress intensity factor ranges ($\Delta K < 5$ $MPa\sqrt{m}$). We will continue enhancing and upgrading the GUI of the computational tool. Additional input and output windows will be added as tool features and capabilities are required. Furthermore, the tool will be implemented in a cloud system to enable remote analysis, eliminating security limitations associated with local systems and providing broader accessibility to users. Furthermore, we implemented the tool on a cloud platform for execution within a virtual environment. Affiliate status will be secured for non-OU users to enable their access to the tool in the virtual environment.

Potential Impacts to Pipeline Safety:

Our tool can now predict the extent of HE in hydrogen transportation through existing gas pipelines. These predictions enable identifying a safe operating range for transporting hydrogen within natural gas pipelines, ensuring material integrity and operational safety.