CAAP Quarterly Report

07/05/2024

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

Contract Number: 693JK32250004CAAP

Prime University:

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Reporting Period: 03/30/2024 – 06/29/2024

Project Activities for Reporting Period:

The project team has continuously maintained the master database to ensure it contains the latest hydrogen embrittlement (HE) data for carbon steel used in pipeline applications (Task 1). As part of this ongoing maintenance, periodic data cleaning is performed to identify and rectify inaccuracies and inconsistencies. By incorporating the experimental data generated through this project, new machine-learning models have been developed to predict the reduction of area and maximum elongation of pipeline steels. Furthermore, the team has conducted laboratory experiments to assess how HE affects the fracture behavior of pipeline steel (Task 2.3). For this evaluation, pre-cracked compact tension (CT) specimens were prepared and subjected to a constant loading rate to determine the material's fracture initiation and fracture toughness. The specimens were pre-cracked using cyclic loading at room temperature. Initially, pre-cracking took longer than expected; our research team improved the setup and developed an efficient procedure to complete the work in a reasonable time while meeting test requirements set by established industry standards for material testing. It was observed that the loading rate slightly impacts fracture toughness tests in hydrogen gas. Therefore, the fracture characteristics of the materials were measured using the standard testing procedure outlined in ASTM E1820. We have compiled several datasets detailing carbon steel fracture behavior, encompassing parameters such as the stress intensity factor and J-integral. We have also investigated the effects of gas composition on X52 carbon steel fracture characteristics. Moving forward, we plan to complete experimental studies on the fracture behavior of steel by varying pressure, temperature, oxygen content, and material type. Moreover, we plan to start experimentally studying the fatigue characteristics of pipeline steel in the next quarter.

To conduct fitness-for-service (FFS) assessments, we have developed a compatibility assessment model that integrates the primary output models from Task 3.2 with standard procedures. This model considers several modes of pipeline failure. FFS assessments and re-ratings of pipelines for pure and blended hydrogen gas are performed using the compatibility assessment model, which incorporates standard procedures and the degraded material properties predicted by the primary output models. We established an efficient and robust algorithm for the assessment model to ensure reliable predictions within a limited computational timeframe.

During this reporting period, our team has submitted several papers for journal publication and conference proceedings. Additionally, four more papers have been prepared and are currently undergoing internal review. Two of these papers are based on experimental measurements obtained in this project using tensile test specimens. The articles present the effects of hydrogen content, pressure, temperature, and oxygen content on the tensile properties of various pipeline steels.

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
Salaries and Wages	$51,048	$15,827	$66,875
Fringe Benefits	$11,894	$5,444	$17,338
Equipment	$3,418	$0	$3,418
Travel	$0	$0	$0
Materials and Supplies	$61	$0	$61
Tuition	$16,534	$0	$16,534
Indirect Costs	$50,562	$11,699	$62,261
Total	**$133,516**	**$32,970**	**$166,486**

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.

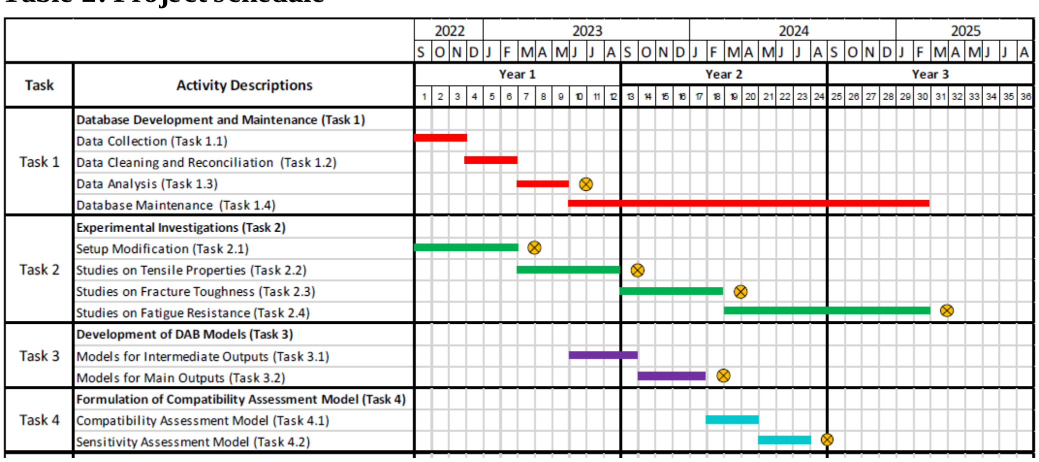
Project Activities with External Partners:

Not applicable.

Potential Project Risks:

By conducting parallel experimental studies (Tasks 2.3 and 2.4), we are compensating for the autoclave manufacturing delay. The delay is not expected to affect the project schedule (**Table 2**).

Table 2: Project schedule



Future Project Work:

In the coming months, the project team will diligently focus on completing fracture toughness experiments (Task 2.3). Beyond gas composition, we will investigate additional factors influencing hydrogen embrittlement in pipeline steel, including working pressure, temperature, material type, loading rate, and aging time. Our objective is to simulate a comprehensive range of real-world conditions. Concurrently, we will conduct fatigue tests using compact CT specimens to assess the impact of various load ratios, load fluctuation frequencies, and prevailing system pressures and temperatures. This investigation aims to elucidate the mechanisms affecting the endurance and reliability of pipeline steels under embrittlement conditions. The insights derived from our measurements will be critical in guiding modifications to existing pipelines to facilitate the safe transport of hydrogen and hydrogen-containing gases. This research will provide valuable knowledge for leveraging pipeline infrastructure to transition to renewable energy resources.

Furthermore, in the coming months, we will continue the development of a model for compatibility for fitness-for-service (FFS) assessments, incorporating key outcomes from Task 3.2 alongside established guidelines (API 579-1/ASME FFS-1 and ASME B31.12). The model addresses various pipeline failure scenarios, such as tensile, fracture, and fatigue damages. It conducts FFS evaluations and adjusts ratings for pipelines carrying pure or mixed hydrogen by employing conventional methods and utilizing the deteriorated material characteristics forecasted by the primary output models. We devised a powerful and dependable algorithm for the model, ensuring it delivers accurate forecasts. Utilizing this algorithm, we created models that aggregate data (such as pipeline material traits, gas mix, and operational parameters), execute both intermediate and primary models in a sequence to estimate the decline in material properties and apply these estimates in the compatibility assessment.

Potential Impacts to Pipeline Safety:

At this stage in our project, our machine-learning algorithms can predict the extent of hydrogen embrittlement (HE) that could happen when hydrogen is transported through existing gas pipelines. Thus, the predictions from our models can help define a safe operating range for transporting hydrogen in natural gas pipelines. To enhance the precision of these models, we'll include new experimental data from our current study and other significant research related to HE.