CAAP Quarterly Report

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Prepared for: *U.S. DOT Pipeline and Hazardous Materials Safety Administration*

Contract Number: 693JK31850006CAAP

Project Title: Predicting Remaining Fatigue Life of a Dent with Corrosion Using Advanced Measurements and Modeling

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Business and Activity Section

(a) Contract Activity

The results from year one research were used to write and submit the following two journal research papers:

- Pfeifer, D., Kim, Jin-Yeon, and Jacobs, L.J., "Nonlinear Rayleigh waves to evaluate plasticity damage in X52 pipeline material," *Mechanical Systems and Signal Processing*, submitted, 2019.
- Fahse, D.N., Levy, K.M.S., Kim, Jin-Yeon, and Jacobs, L.J., "Comparison of changes in nonclassical and classical acoustic nonlinear parameters due to thermal aging of 9Cr-1Mo ferritic martensitic steel," *NDT&E International*, submitted, 2019

Ongoing research activities focused on: quantifying the variability of the measured nonlinearity parameter in two different samples of the legacy pipeline material; and in the measurement of the nonclassical nonlinearity parameter, α for comparison with the previously measured classical nonlinearity parameter, β.

(b) Status Update of Past Quarter Activities (Fifth Quarter Activities)

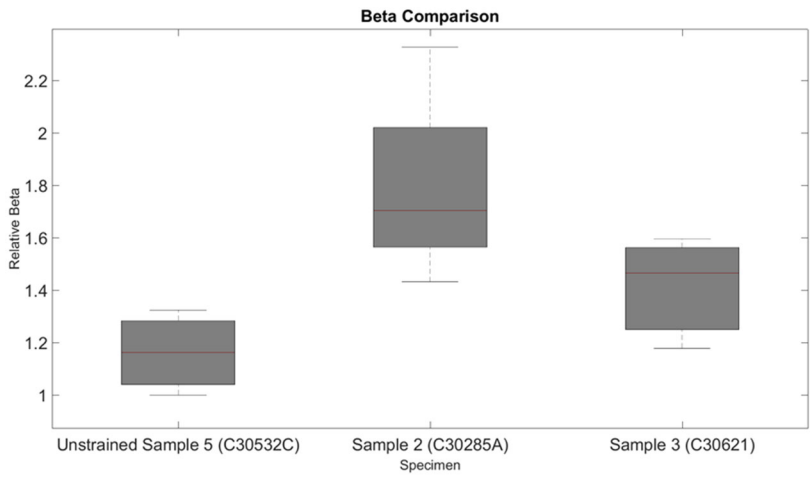
The primary activities in the fifth quarter were on Tasks 1, 2 and 5. Task 1: Baseline measurements on virgin specimens from three different pipe grades to quantify the effect of material variability on the measured NLU parameter, β; Task 2: NLU measurements on statically loaded (or prestrained) specimens to quantify the effect of material plasticity on the measured NLU parameter, β; and Task 5: Development of a predictive model for the measured NLU parameter, β.

Measured the NLU parameter, β in two different undamaged legacy materials, to continue to quantify the inherent state of material nonlinearity in the undamaged material. In addition, measured both the classical and nonclassical nonlinearity parameters in a complementary material system, 9Cr-1Mo steel, to better quantify the relationship between microstructure changes during plastic deformation, and these measured nonlinear parameters.

(c) Cost share activity

No cost share activity this quarter. Personnel services support/expenses from Georgia Tech: support for PI Laurence Jacobs, Dr. Jin-Yeon Kim (doctoral level Research Scientist) and Katie Scott Levy (PhD student) with an approximate cost of 10% total.

(d) Task 1: Baseline NLU measurements on virgin specimens from three different pipe grades

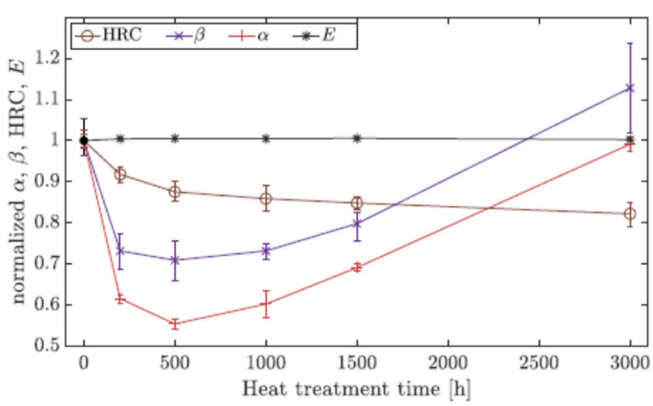


Measured the classical NLU parameter, β in two different undamaged legacy materials provided by Fleet Technology in the fifth quarter. The results show a significant level of variability in the undamaged material, with changes on the order of 20% within individual materials. These results are shown in the Figure at the left.

Task 2: NLU measurements on statically loaded (or prestrained) specimens to quantify the effect of material plasticity on the measured NLU parameter, β.

Continued measurements on statically loaded legacy specimens, measuring the classical nonlinearity parameter, β as a function of plastic strain. Summarized these results in a paper submitted to *Mechanical Systems and Signal Processing* in December 2019.

Task 5: Development of a predictive model for the measured NLU parameter, *β*.



Measured both the classical, β and nonclassical, α nonlinearity parameters in a complementary material system, 9Cr-1Mo steel to better understand the relationship between changes to the microstructure during plastic deformation and the measured nonlinear parameters. The results shown in the Figure to the left included complementary Rockwell Hardness and elastic modulus, E. This figure makes it clear that both the classical and nonclassical nonlinearity parameters follow similar patterns, even though they are sensitive to different changes in the microstructure – the classical second harmonic generation from dislocations, as opposed to the hysteresis from hard particles such as precipitates present in a softer matrix, respectively. These results are being used to develop the predictive model and were summarized in a paper submitted to *NDT&E International* in November 2019.

1. Background and Objectives in the 5th Quarter

1.1 Background

Summarized the results from the first year's research and submitted two papers for possible publication as archival, peer-reviewed journal articles. Further quantified the inherent variability of the classical nonlinearity parameters, β in this legacy pipeline material. Developed a second measurement procedure based on nonlinear resonances to quantify a complementary nonclassical nonlinearity parameter, α.

1.2 Objectives in the 5th Quarter

This variability in the measured β is much larger than that present in more modern material systems, which will require the implementation of extremely accurate measurement procedures for in-service monitoring. It is critical to understand if changes in the measured acoustic nonlinearity parameter β due to this material variability will be greater than the anticipated changes due to the accumulated fatigue and plastic damage.

1. Experimental Program in the 5th Quarter

2.1 Experimental design

Demonstrated the ability to make NLU measurements of both β and α to enable the development of a predictive model in Task 5.

2. Results and Discussions

The results continue to show the potential effectiveness of using nonlinear parameters to monitor changes in microstructure of pipeline material due to the plastic damage of a dent. We continue to refine the experimental measurement procedures to reduce the influence of the inherent material variability in these legacy materials. The multi-physics approach of measuring two complementary nonlinear parameters (both β and α) shows promise for the development of a predictive model. Doctoral student Katie Scott Levy completed the resonance measurements of α and she graduated in December 2019. We identified a new masters level student who will start work on the project in the 6th quarter.

3. Future work

Finish quantifying the material variability in Task 1, and continue with nonlinear ultrasonic measurements in the prestrained specimens in three different legacy materials (both static and fatigue.