CAAP Quarterly Report

Date of Report: *Dec. 3, 2015*

Contract Number: *DTPH56-13-H-CAAP02*

Prepared for: *DOT*

Project Title: *Scaling and Self-Sensing in Composite Repairs of Corrosion Defects*

Prepared by: *The University of Tulsa*

Contact Information: *Michael W. Keller, mwkeller@utulsa.edu, 918-631-3198*

For quarterly period ending: *November 31, 2015*

Business and Activity Section

(a) Generated Commitments

There has been no change in project participants or other contracts.

Supplies	Cost
McMaster - Testing system transformer	687.55
Supplies for testing system	583.13
Supplies for testing system	71.33
Hose fittings and couplings	67.63
Supplies for testing system	449.85
Coupon Testing Supplies	87.83

(b) Status Update of Past Quarter Activities

During the last quarterly period we have

1. Repaired fatigue testing system
2. Completed fabrication of large scale test vessel
3. Continued self-sensing study

Small-Scale Sample Testing

Small scale testing continued during this quarter and we have nearly completed one set of the small scale test specimens. Unfortunately, the hydraulic testing system has had several additional failures related to seals and a radiator. At this point, we have decided to stop using the hydraulic test system and have moved to a test system based on a high-pressure pump (pressure washer). This system has been working quite well with the related through-wall program and we expect it to work more reliably than the hydraulic system. This system is now up and running and fatigue testing is proceeding.

Large Vessel Fabrication

Large vessel fabrication is mostly completed as seen in Figure 1. The four patch flaws were rolled and then welded between 42 inch piping spacers. The welds are being ground flat to ensure that the installs are completed on a smooth surface. The installs of these repairs will be scheduled for the end of

January 2016 and the beginning of February. Based on the current fatigue performance of the specimens that have been tested, we expect that most, if not all, repairs will go to the 100,000 cycle runout value. The redesigned fatigue system used to test the small scale samples will be used to test this large vessel as well.

Figure 1: Picture of the as fabricated vessel. Diameter is 42 inches.

Self-Sensing Research

Confirm Quasi-static testing behavior.
Based on our preliminary data for the resistive sensing presented in the previous quarterly report, we have been moving to make the approach more robust and repeatable. A   Figures 2 and 3 show the current resistance measurement approach we are adopting and images of the failure surface of the sample.

Figure 2 set-up of resistance wires

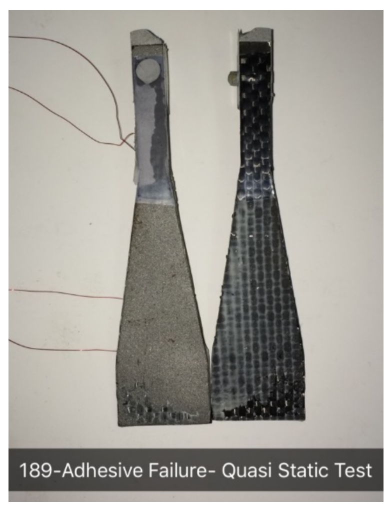

Figure 3 post test image.

Figure 4 shows the applied load and resistance measurements vs displacement change of the sample in Figures 2 and 3 sample during a quasi-static test. For this specimen the wires applied to the composite were taped to a region of material that had been surface sanded. Prior to this approach, we had been applying wires directly to the top of the composite and we were having issues with repeatability. This was because we were relying on exposed carbon to complete the circuit to enable resistance measurements. By sanding the top surface and exposing some of the reinforcement, we are able to make much more reliable electrical connections. The resistance chance in Figure 4 is highly correlated to the crack propagation.

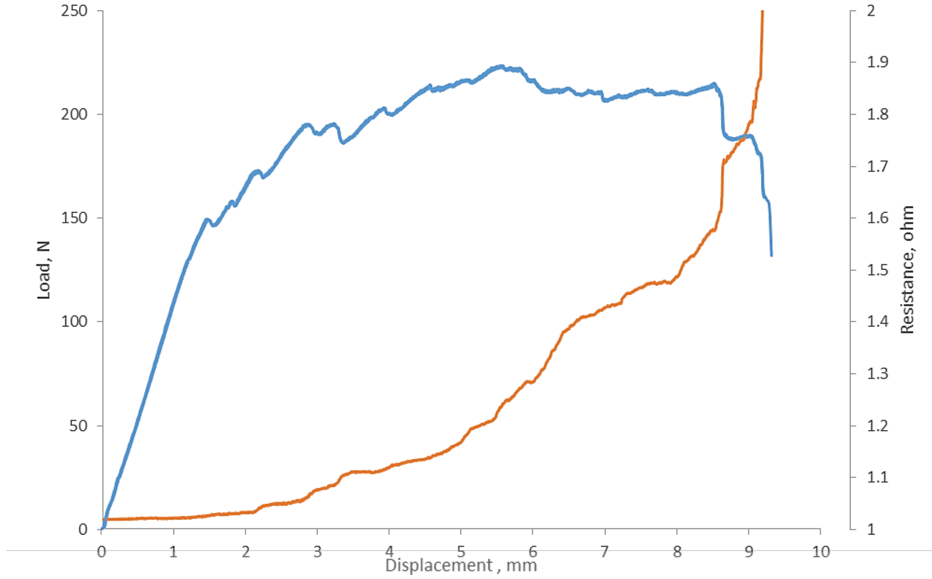

Figure 4 Quasi-Static test's result for sample # 189

Co-fabricated electrodes

While the surface-sanding approach was successful and yielded repeatable results, this effectively damages the composite and will not be attractive for installers. To address this issue, we have also investigated embedding wires directly at the top surface of the composite during fabrication. This allows us to ensure that a bare wire is good contact with the reinforcement. Figure 5 shows a sample, with close up images of the embedded wires.

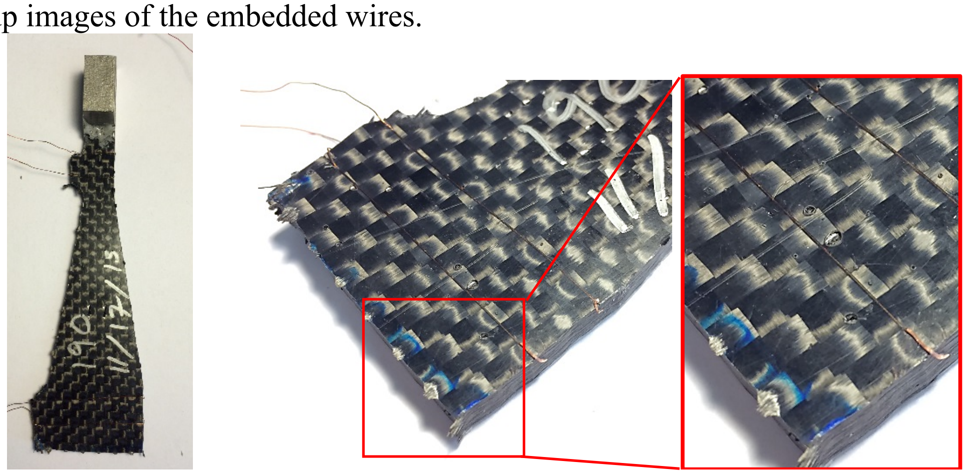

Figure 5 Sample # 190 A) full sample image B) close image of two wires embedded in composite.

The figure 6 shows the behavior of a sample fabricated with embedded wires. This approach yields approximately the same resistance change measurement as the sanded wires and therefore we expect that the two approaches are equivalent. For all the measurements above, we ran a 4-point resistance measurement using a constant current approach. The constant applied current is similar to what would be expected in impressed current protection systems.

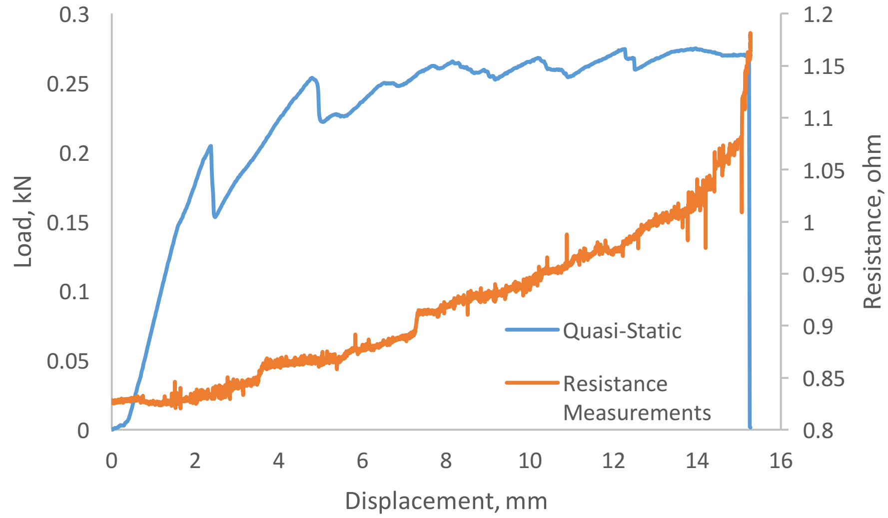

Figure 6 Quasi-Static results for sample monitored with embedded wires.

Fatigue monitoring using sanded area

We performed another fatigue test using the sanded area approach to validate that this procedure improved the reliability of the results.

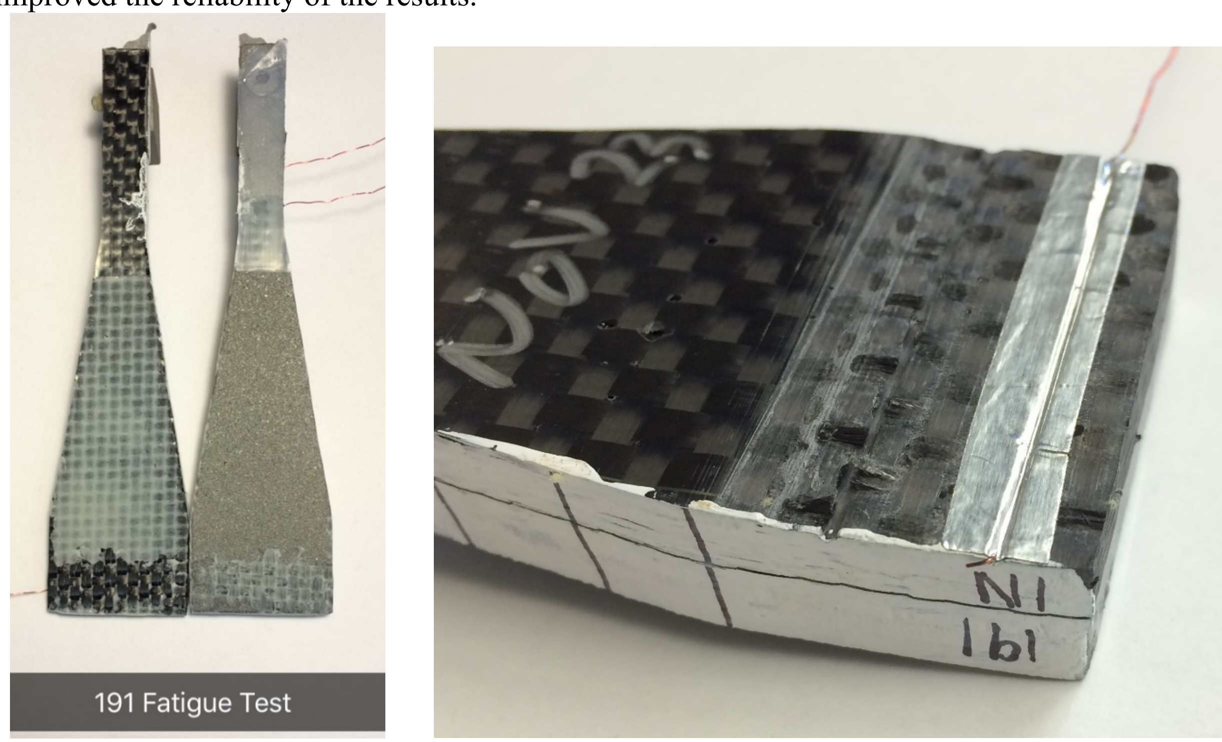

Figure 6 sample # 191 A) after fatigue test B) Close image of sand area and attached wire

Figure 7 shows the crack length propagation, optical reading, and resistance measurements vs the fatigue cycles for this sample. Failure was approximately 7000 cycle for a loading of 50% K_{IC}. Based on the full-scale through-wall tests that we have performed, this fatigue life is on the same order of magnitude. There is some scatter in the resistance measurements in Figure 7, but a clear trend of increasing resistance as the crack propagates is visible.

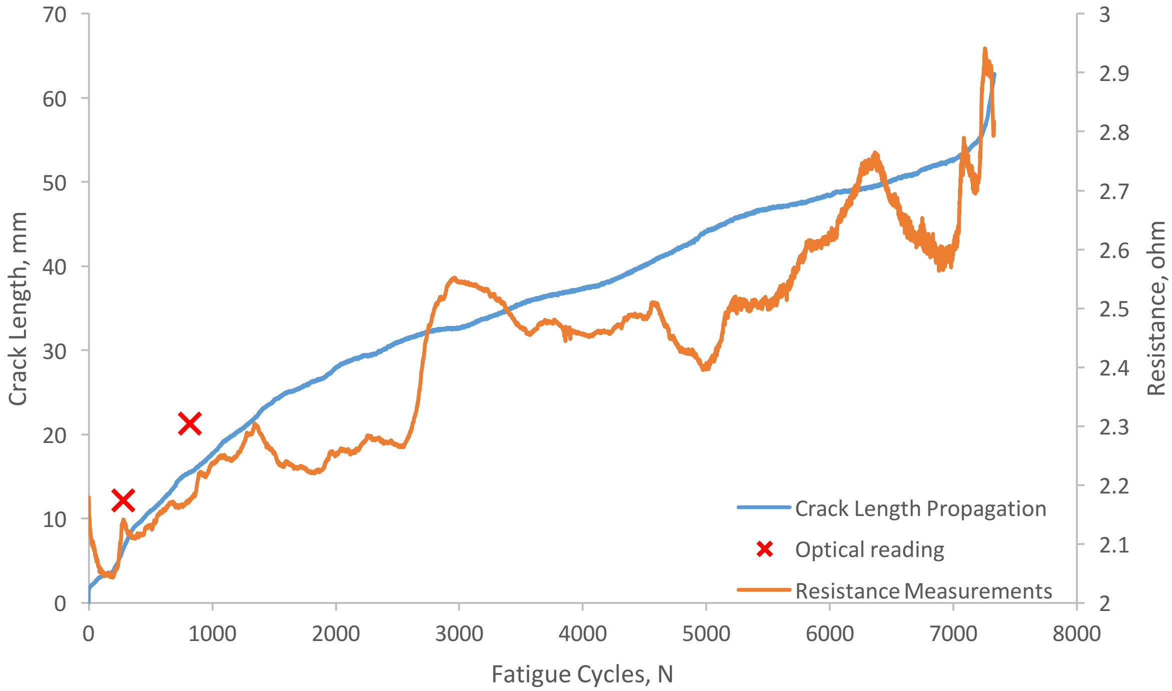

Figure 7 Crack length propagation and resistance measurement vs fatigue cycles.

Now that we have validated this approach for the coupon-level samples, we are planning on moving to testing an initial full-scale sample. This will include developing installation procedures for the sensing wires and testing protocols.

DIC Evaluation of composite repairs

While we were rebuilding the fatigue system, we were able to perform some initial full-field displacement and strain measurements on the composite repairs.

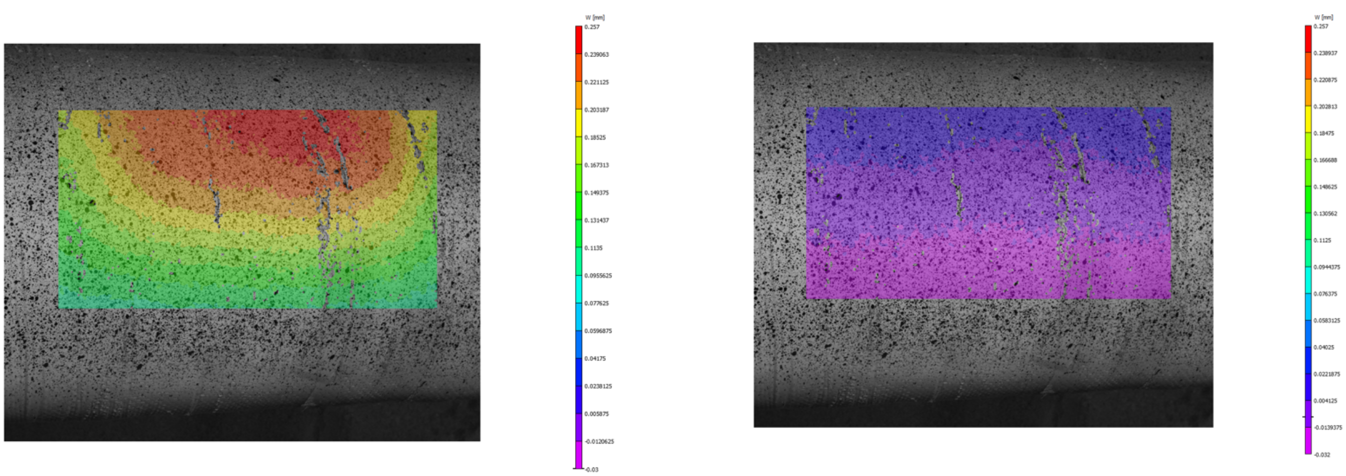

Figure 8: DIC images of a pressurized (left) and unpressurized (right) full-encirclement specimen.

Figure 8 shows a DIC analysis for a specimen that was pressurized and then unpressurized. The deformation of the region above the flaw is clearly visible in the deformed image as a red shaded contour. We are working though imaging and analyzing several specimens for both patch and full-encirclement repairs to investigate differences in the full-field behavior of the composites. These full-field techniques will be compared to the strain gage evaluations to provide additional details on the repair performance.

***(c)* Description of any Problems/Challenges**

We are still facing schedule delays for fatigue testing the small-scale pressure vessels. This delay has been exacerbated by the mechanical issues associated with the testing system. There are no other issues at this time. Because of the timing of the graduate student hire, we have requested a no-cost extension for this project. This extension should help ease the scheduling issues.

***(d)* Planned Activities for the Next Quarter –**
Since we are in the testing phase, our planned activities for the next quarter are similar to those of last quarter (ending December 1.)

1. Complete small scale fatigue testing.
2. Complete fabrication of large-scale test vessel and pressure system.
3. Perform an initial on-specimen self-sensing test during the fatigue testing.
4. Schedule large-scale specimen installs and testing.