Development of a Sensor for Monitoring Fatigue Crack Growth in Steel Members

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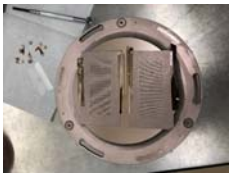
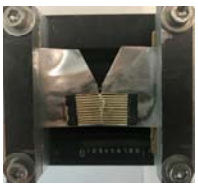
Summary

Motivation and Background



Fabrication Process



Results and Future Work

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Motivation and Background

- Fatigue is the weakening of a material caused by repeatedly applied loads
  - Very common in bridges
- 2015 U.S. Department of Transportation report to congress
  - Average bridge age = 43 years
  - Over 18,000 fracture critical bridges throughout the U.S.
- The design of most of these older brides did not account for fatigue

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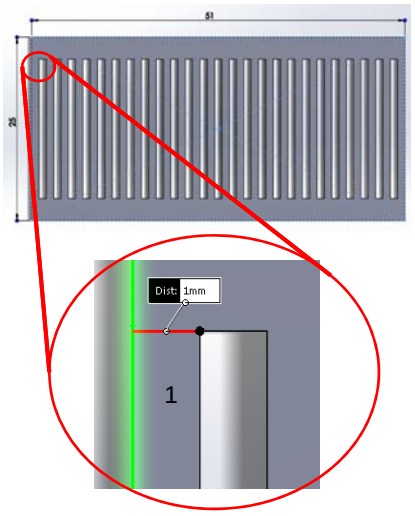
Design

- Initially decided on a comb-like sensor
  - 1-in by 2-in
- On a paper substrate
- Designed for the American Society for Testing and Materials (ASTM) E647 metal fatigue test



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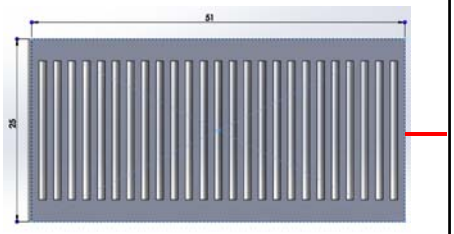
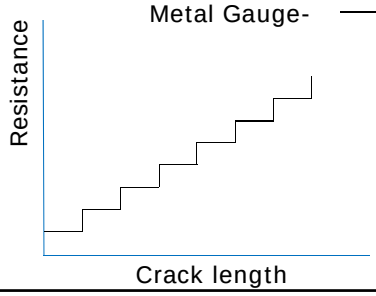
Operating Principles

- Sensor is adhered to a structure in the path of a known crack
- Measure the resistance across the sensor
- Crack propagation will break wires
- Broken wires will increase the resistance of the sensor in a stepwise manor





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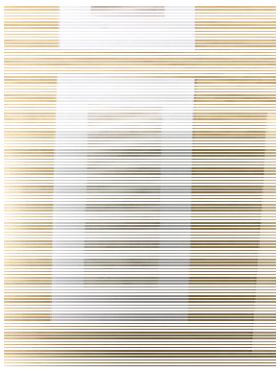
Fabrication Process – Shadow Masks

- Using a VersaLaser 60 W laser, shadow masks of the sensor were cut out of assorted paper types
- Two stage deposition process



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Fabrication Process – Metal Depositing

- Masks were placed in a vacuum oven at 150° C for 90 minutes to reduce outgassing during deposition
- Using a Physical Vapor Deposition (PVD) Chamber, the following process was used to deposit 100 nm of copper metal in the sensor configuration




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Fabrication – Screen-Printing

- Conductive ink
  - 2:1, Elmer's Glue:Sigma Aldrich graphite powder
  - One percent by weight of colloidal silver
  - Add deionized water until desired consistency


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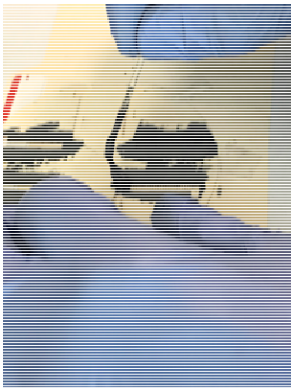
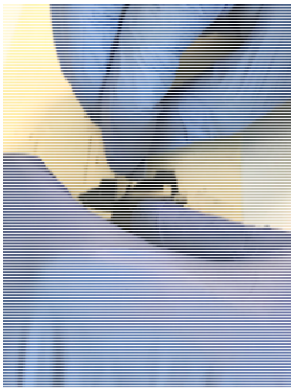
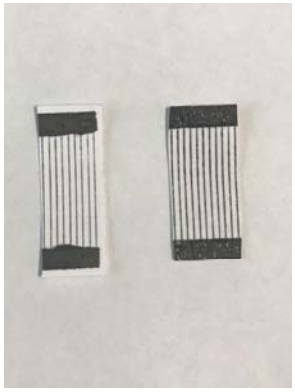
Fabrication – Screen-Printing (cont.)

- Using the same shadow masks from the PVD method
- The following method was used to screen-print graphite crack sensors

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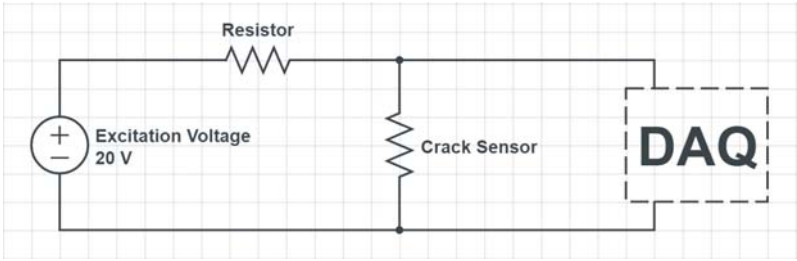
Testing – Circuit Construction

- TraNET 204S Data Acquisition System records voltage, time series
- We used a voltage divider circuit to convert changes in resistance to changes in voltage
- As sensor elements break, sensor resistance increases, resulting in increasing voltages recorded by the DAQ



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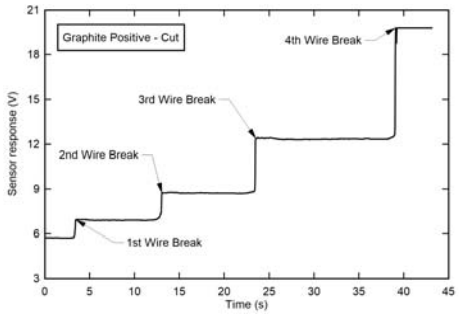
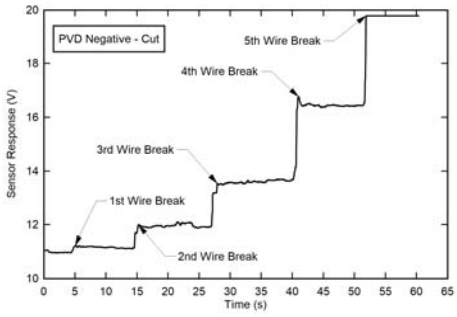
Testing – Cut Test

- Each sensor type was connected to the test circuit
- Using a ceramic knife, wires were individually cut to simulate a propagating crack

Graphite Sensor



PVD Sensor



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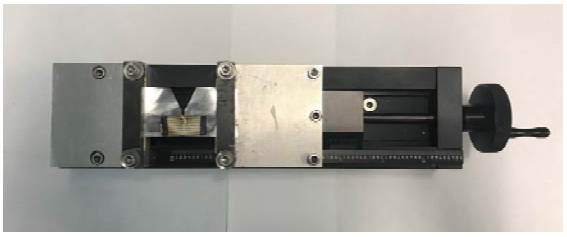
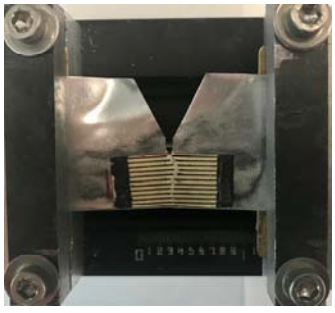
Testing – Tear Apparatus

- Looking forward to (ASTM) E647 fatigue analysis test of a steel plate
- Developed a screw driven tensioner to simulate a slow growing fatigue crack





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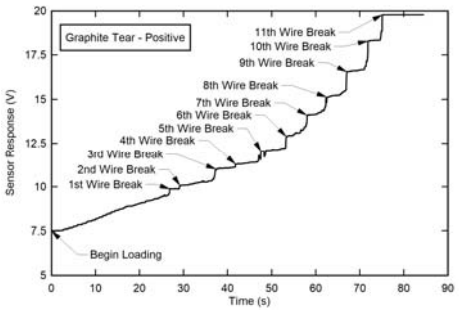
Testing – Tear Test Results

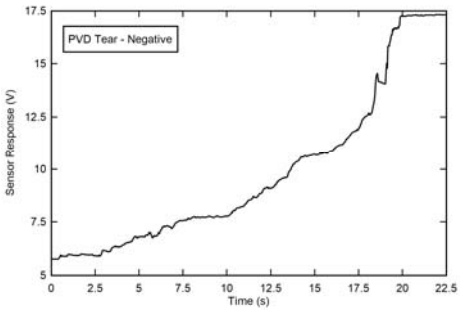
Sensors were adhered to aluminum coupons with superglue and torn in the apparatus to simulate a fatigue crack

Graphite Sensor (11 elements)



Clearly displays a loading zone followed by 11 jumps in voltage

PVD Sensor (11 elements)



PVD sensor is extremely sensitive to strain effects and does not display discreet changes

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Summary and Conclusions

- An inexpensive crack propagation sensor was developed and tested
- Correlated step increases in resistance of the sensors to crack growth
- Graphite sensor was cheapest to manufacture and produced best results

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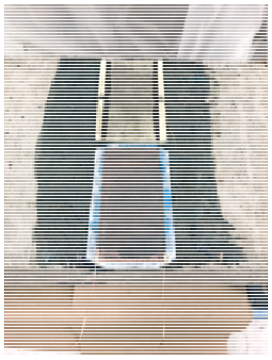
Future Work

- Testing our sensor on a concrete and steel fatigue test specimen (ASTM E647)
- Creating a conductive substance that can be used in an inkjet printer
  - Print crack sensors to any size and dimension



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Questions?