Durability and Survivability of Piezoelectric Wafer Active Sensors Mounted on Aluminum Structures for Aerospace Vehicle Health Monitoring

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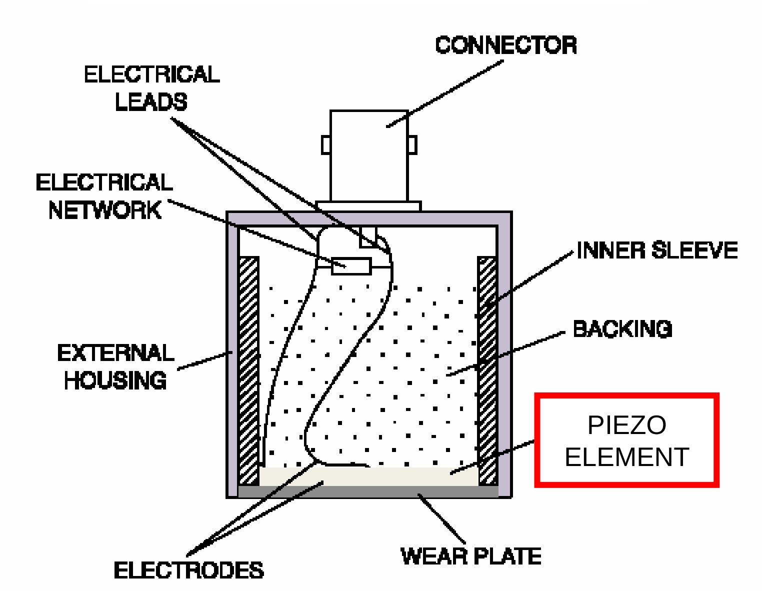
– Air Force Research Laboratory contract through Universal Technologies, Inc.
– Dr. Blackshire, Dr. Nagy

Outline

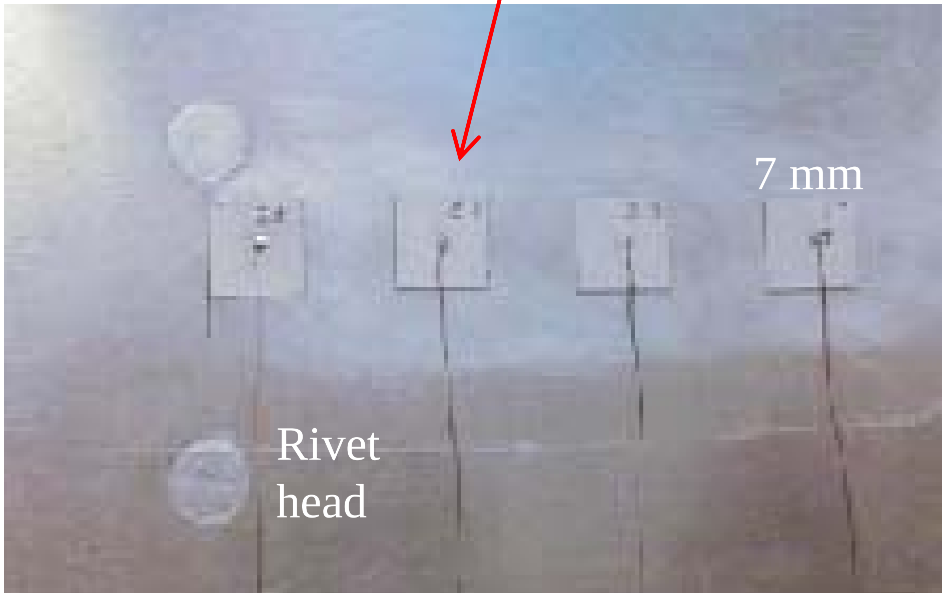
- Introduction to piezoelectric wafer active sensors (PWAS)
  - SHM
  - E/M Impedance
- Durability and survivability of PWAS
  - Temperature cycling
  - Outdoor exposure
  - Submersion exposure
  - Large strains and fatigue loads
- Conclusions

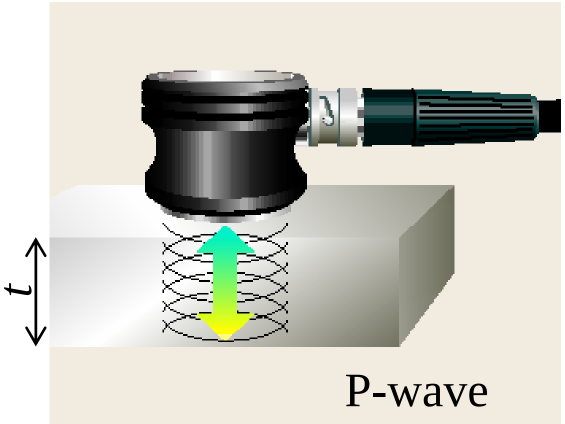
Piezoelectric Wafer Active Sensors (PWAS)

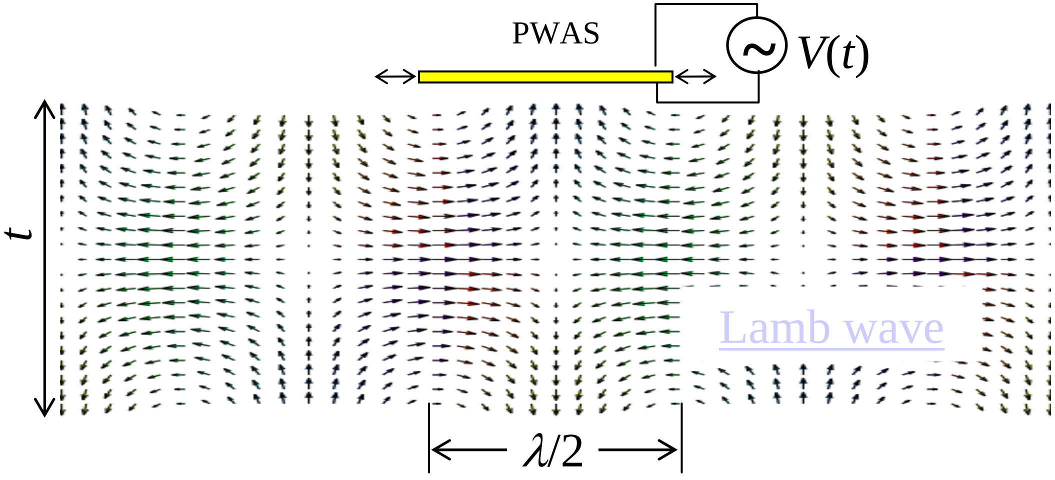
Conventional ultrasonic transducer



PWAS







SHM Technology

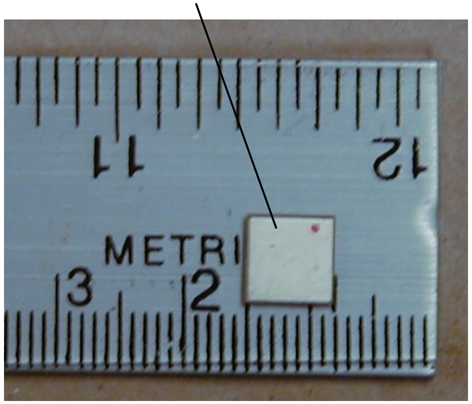
Passive Sensors

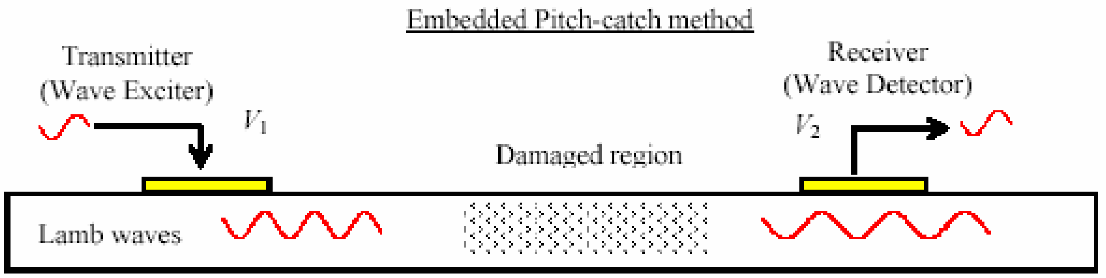
- Monitor the health of the structure over time
- Sensor can “listen” to the structure but can not interact with the structure

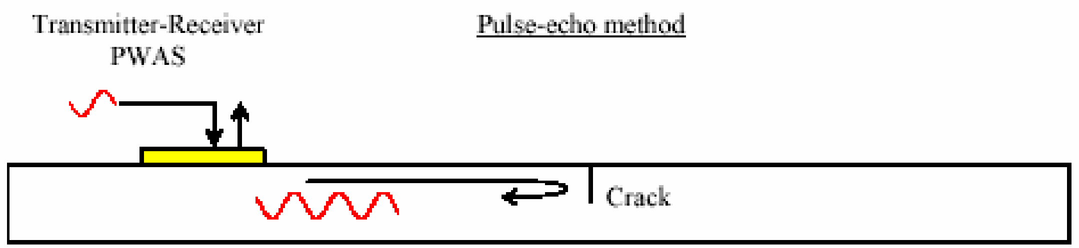
Active Sensors

- Interact with the structure by sending a signal and then “listen” to the structure’s response

PWAS

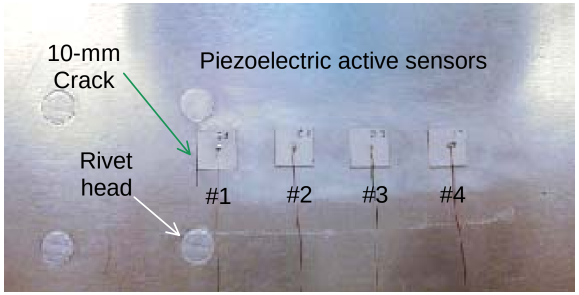


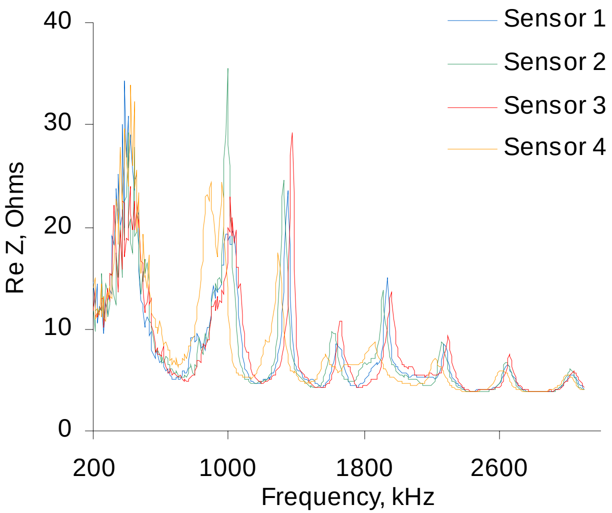




Impedance-based Structural Health Monitoring

- New Structural Health Monitoring (SHM) method.
- Real-time structural damage assessment.
- The electrical impedance of the PZT material can be directly related to the mechanical impedance of a host structural component.
- The change in the structure’s impedance is attributed to the change in integrity of the structure due to damage.
- The real part of electric impedance is more reactive to damage or changes in the structure’s integrity than the imaginary part
- Electromechanical Impedance is Quality Control Method

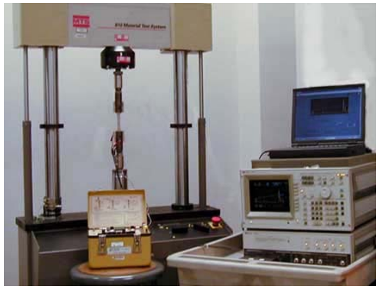


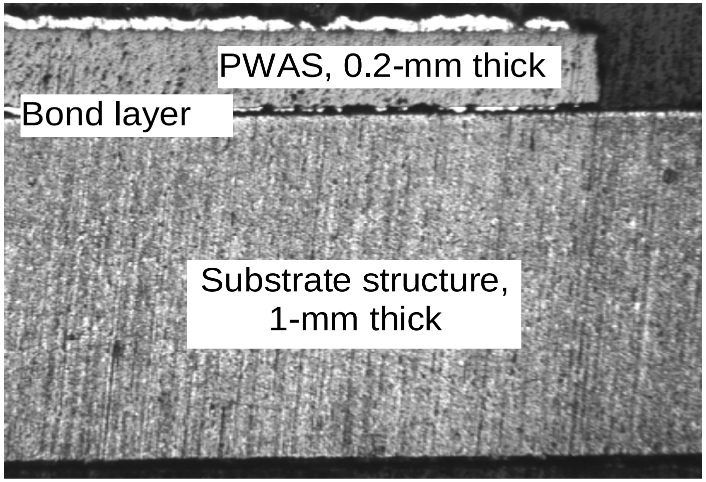


From Dr. Giurgiutiu and Dr. Zagrai’s paper

Objective

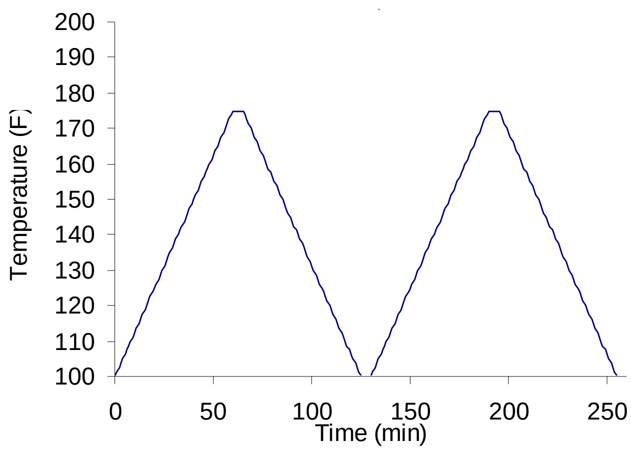
- Explore the durability and survivability issues on PWAS associated with various environmental conditions and fatigue
- Improve properties, layer deteriorates in time under environmental attacks (temperature, humidity, etc.).
- Improve properties, layer deteriorates in time under fatigue attacks

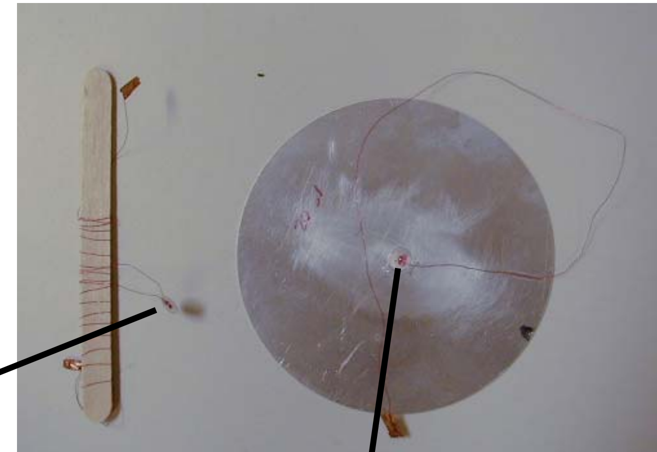


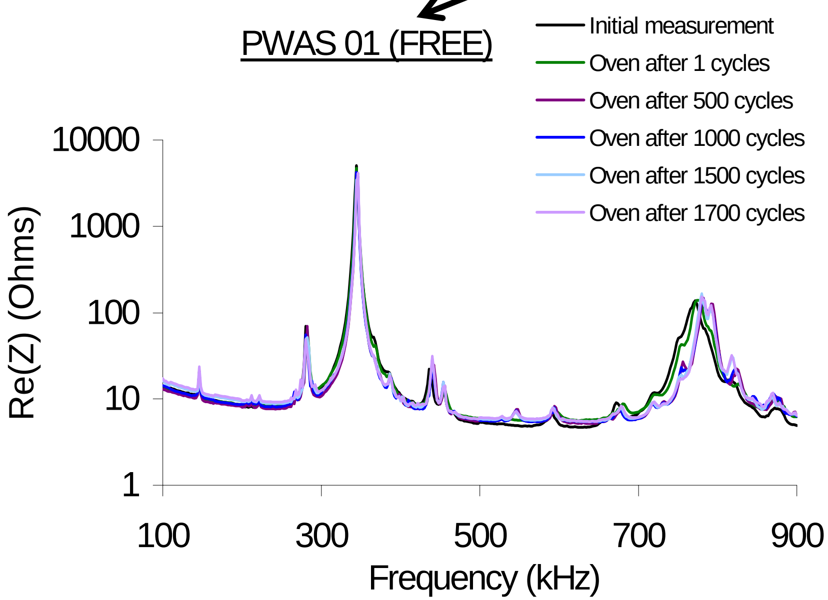


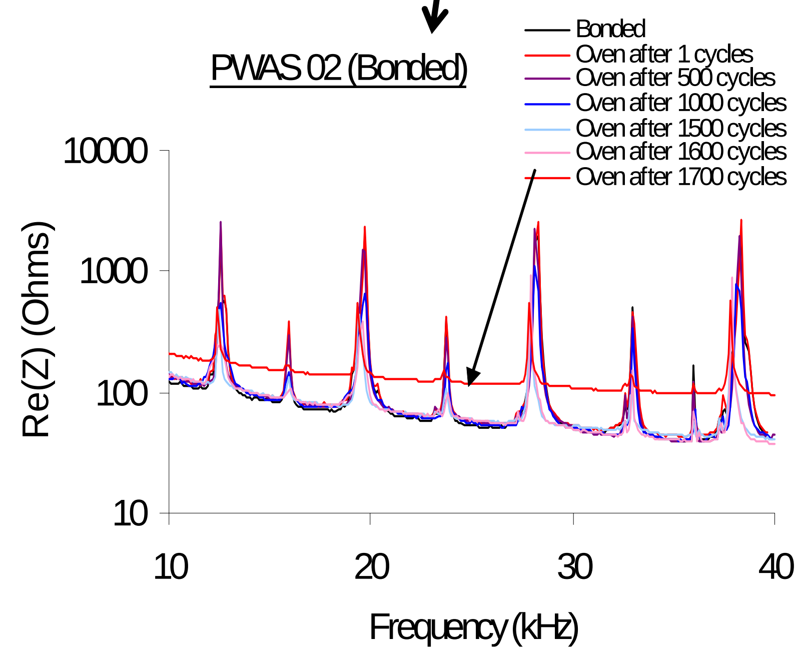
PWAS-structure bond layer

PWAS Durability under Thermal Cyclic



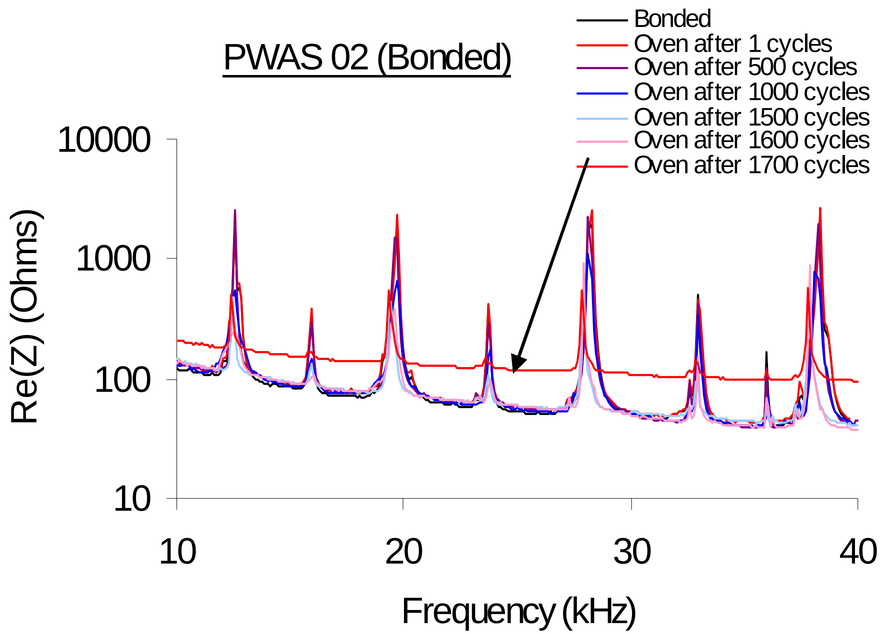




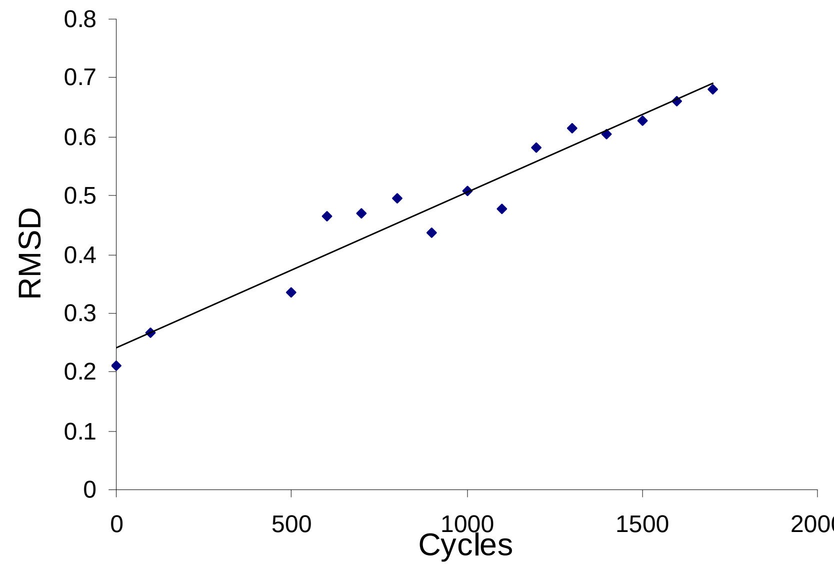


Damage Index

- Development of suitable damage metrics and damage identification algorithms
- The damage index is a scalar quantity that serves as a metric of the damage present in the structure.
- RMSD



$$RMSD = \sqrt{\frac{\sum_N \left[\text{Re}(Z_i) - \text{Re}(Z_i^0) \right]^2}{\sum_N \left[\text{Re}(Z_i^0) \right]^2}}$$

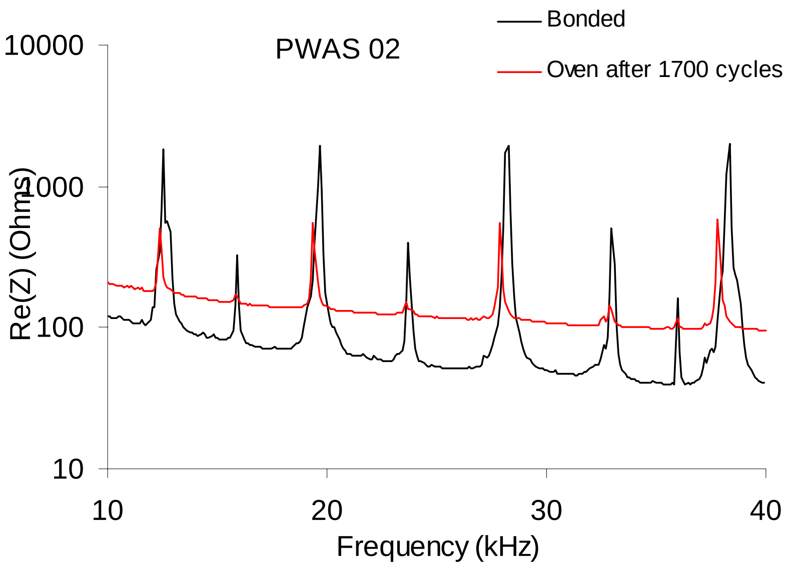


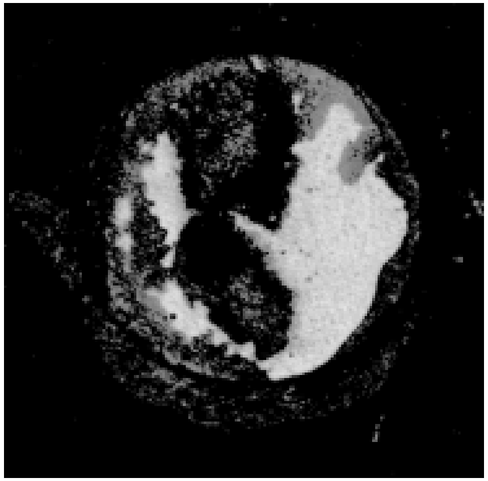
Acoustic Microscope Imaging

E/M Impedance

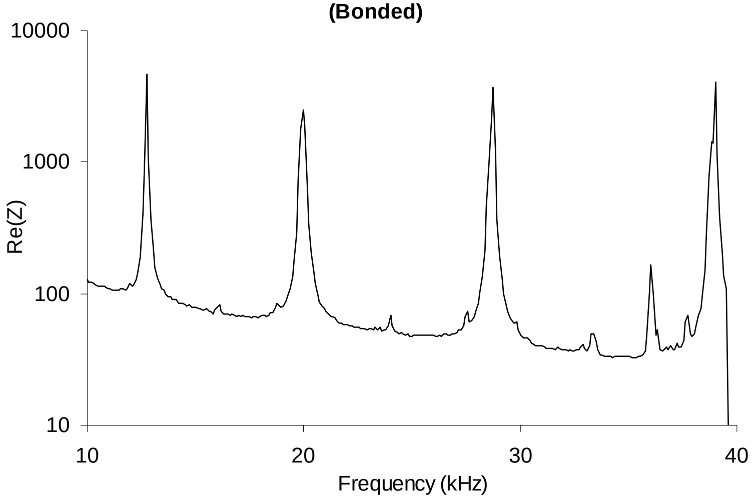
Adhesive/PWAS

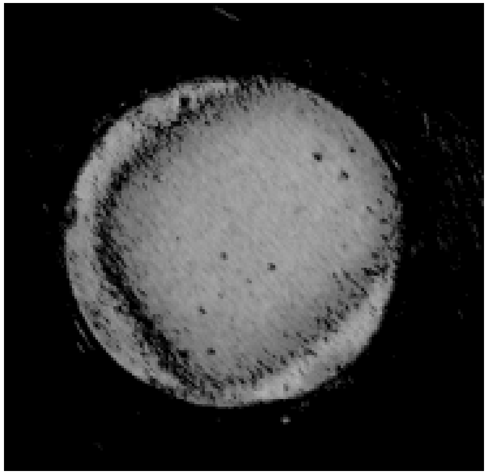
“Bad”
PWAS 02





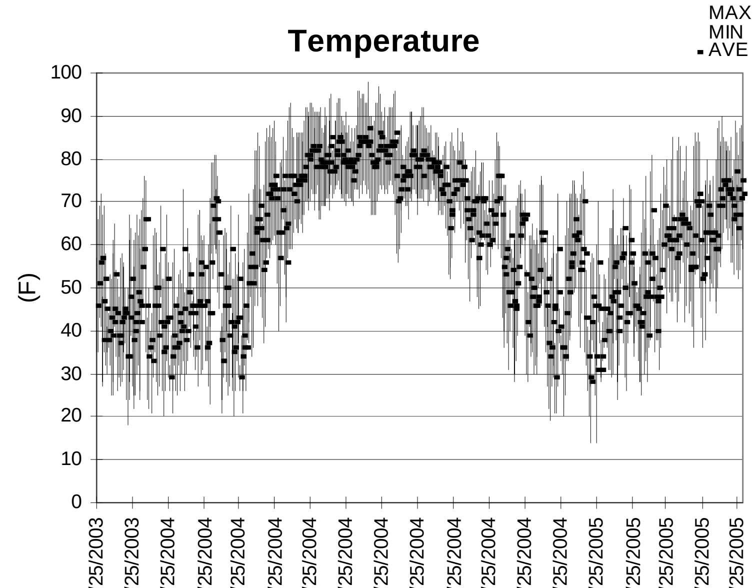
“Good”
PWAS

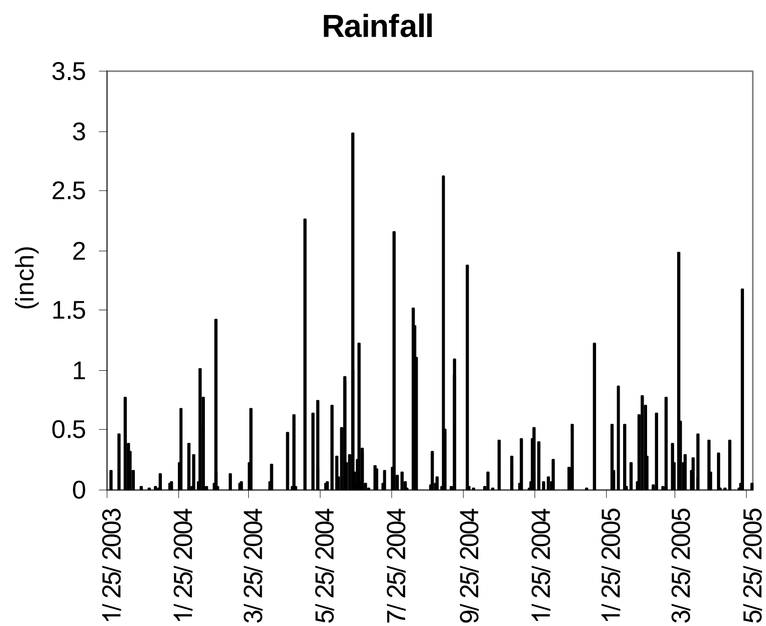




Scanning Area:
10mm x 10mm
Collaboration with Prof. Nagy

Outdoor Exposure of PWAS

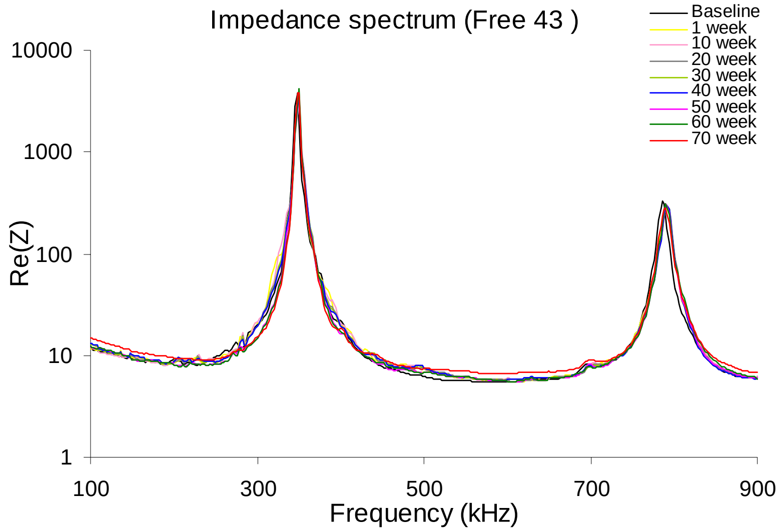


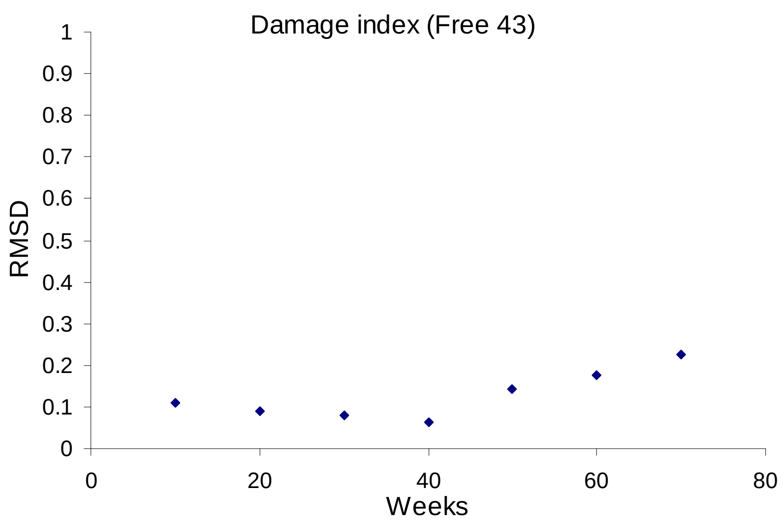


		Adhesive	
		M-Bond 200-cyanoacrylate adhesive with catalyst	M-Bond AE10-2-part 100% epoxy system adhesive
Protective coating	No coating	PWAS-22	PWAS-33
	M-Coat A-Polyurethane	PWAS-23	PWAS-34
	M-Coat C-Silicon	PWAS-27	PWAS-35
	M-Coat D-Acrylic	PWAS-28	PWAS-36

Free PWAS Impedance Spectrum under Outdoor Exposure

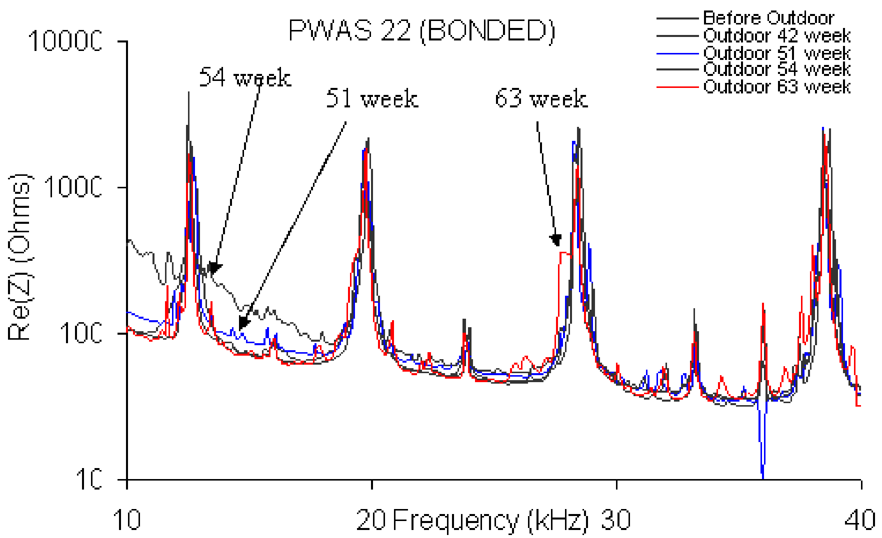
- "Settling in" effect.
- No significant change
- Damage index shows the impedance spectrum remains constant.

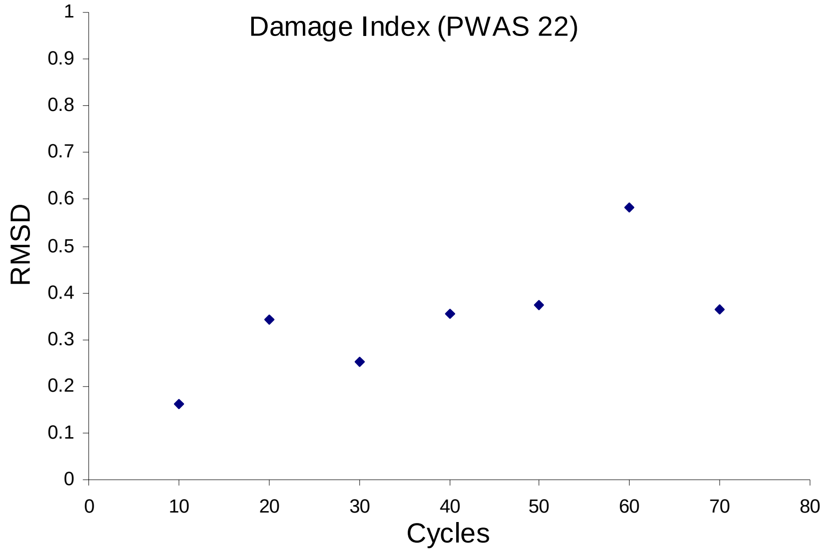




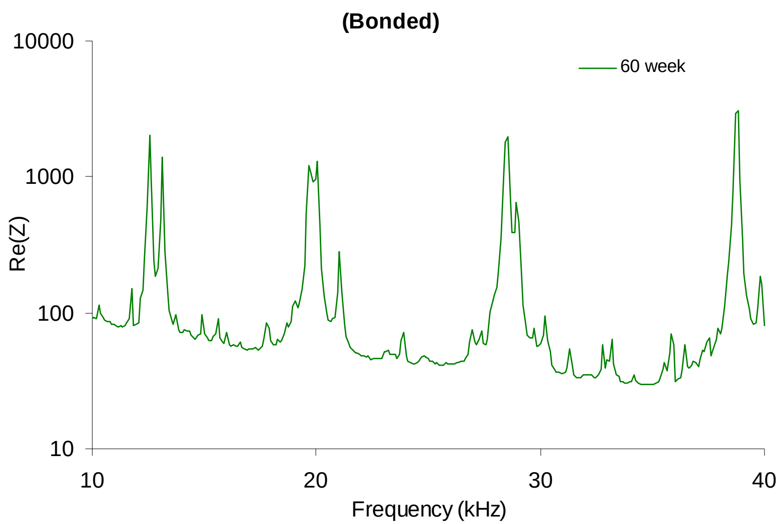
Bonded PWAS Impedance Spectrum under Outdoor Exposure

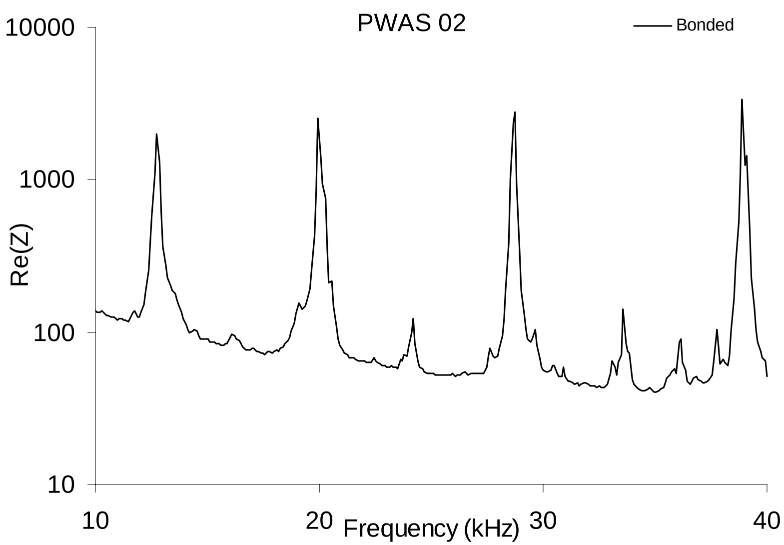
- "Settling in" effect.
- Significant change has been recorded.
- Damage index shows the impedance changes.

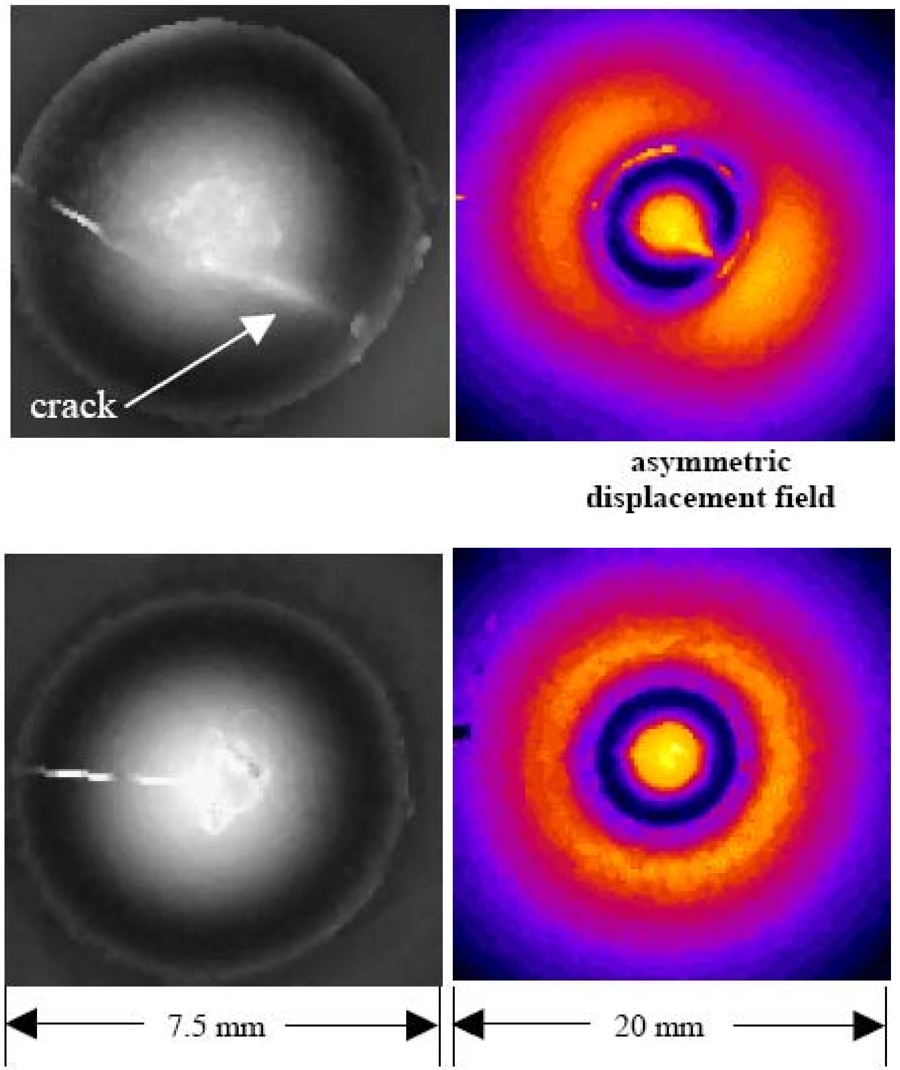




Displacement Field Imaging







Collaboration with Dr. Blackshire

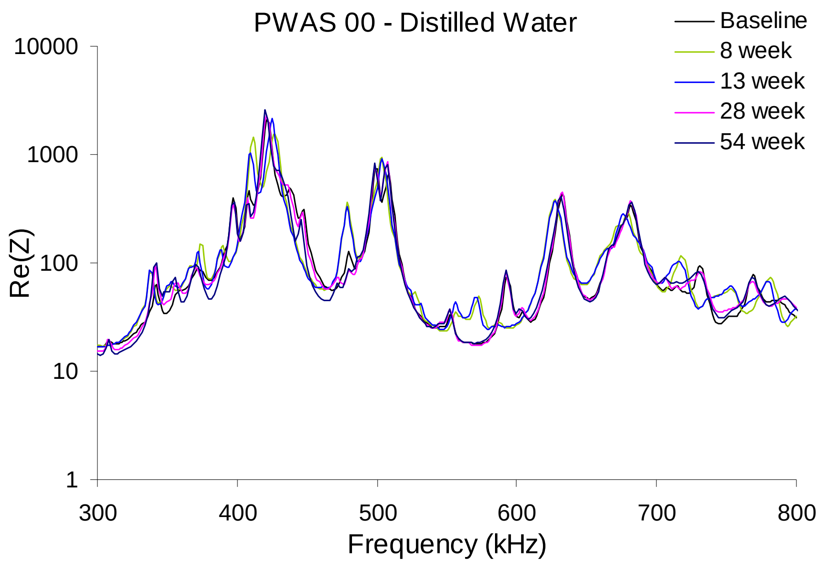
PWAS submersion tests

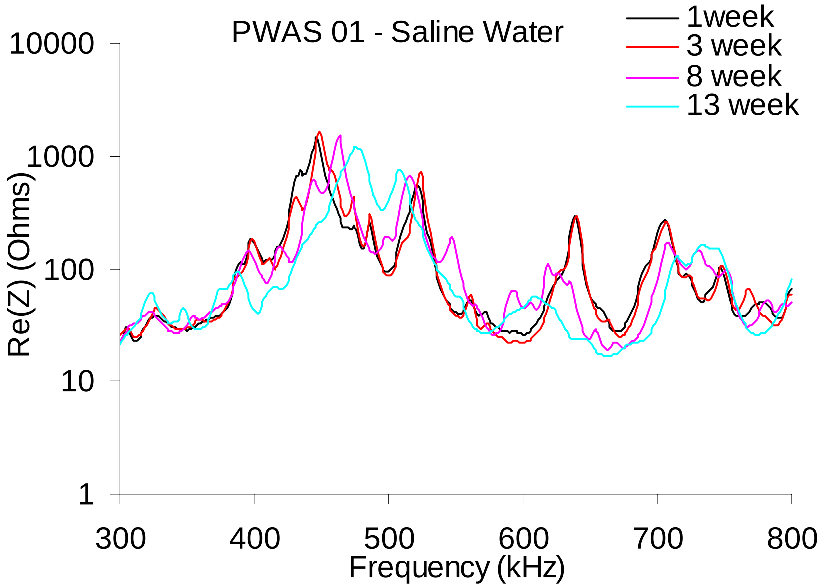
- Distilled water
- Saline solution
- Hydraulic fluid MIL-PRF- 83282 Synthetic hydrocarbon
- Hydraulic fluid MIL-PRF- 87257 Synthetic hydrocarbon
- Hydraulic fluid MIL-PRF- 5606 Mineral
- Aircraft lube oil MIL-PRF-7808L Grade 3 Turbine engine synthetic
- Aviation kerosene

- RESULTS: 60 weeks without failure except in saline solution which failed after 15 weeks

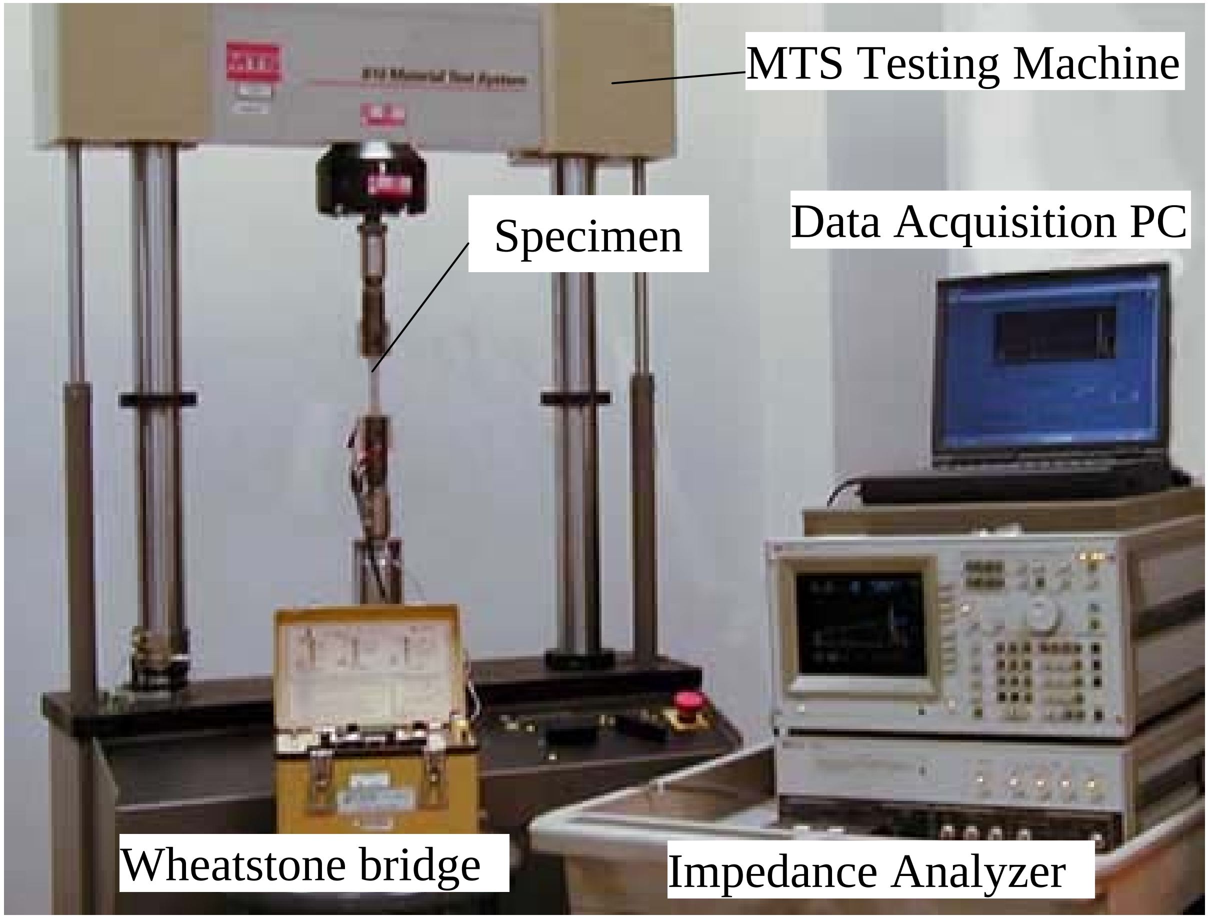
PWAS Impedance Spectrum under Submersion Exposure

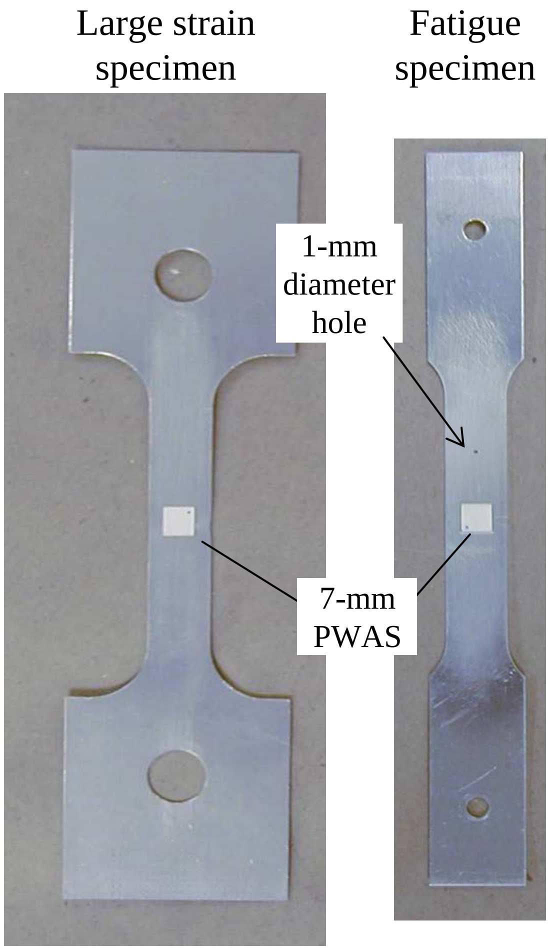
- A little impedance changes in distilled water
- The PWAS submerged in saline solution survived only a little over 85days due to the detachment of the soldered connection
- The corrosive effect of the saline solution.



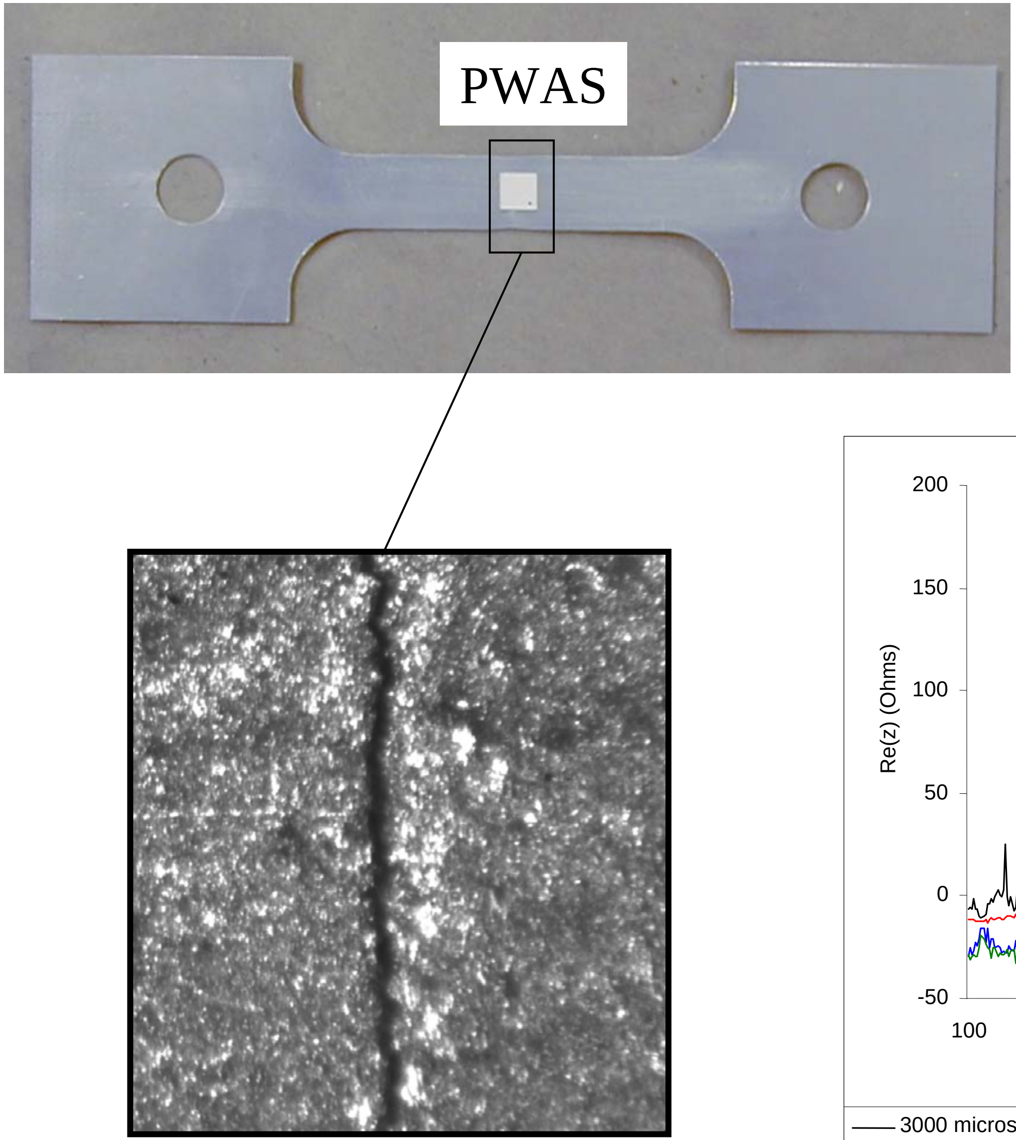


Large Strain and Fatigue Testing



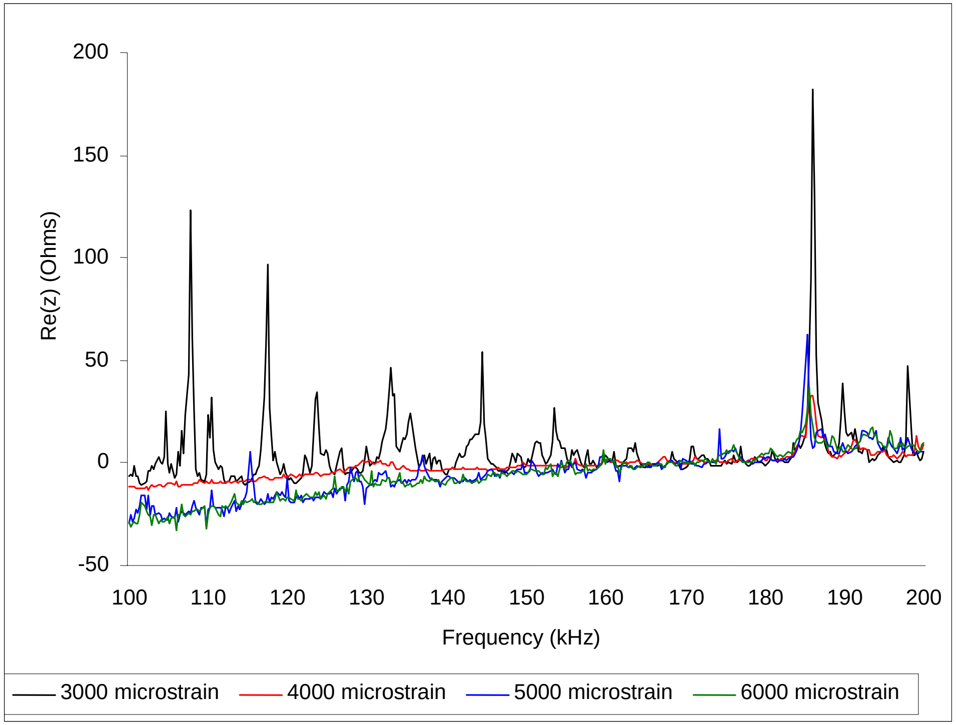


Large-Strain PWAS Testing

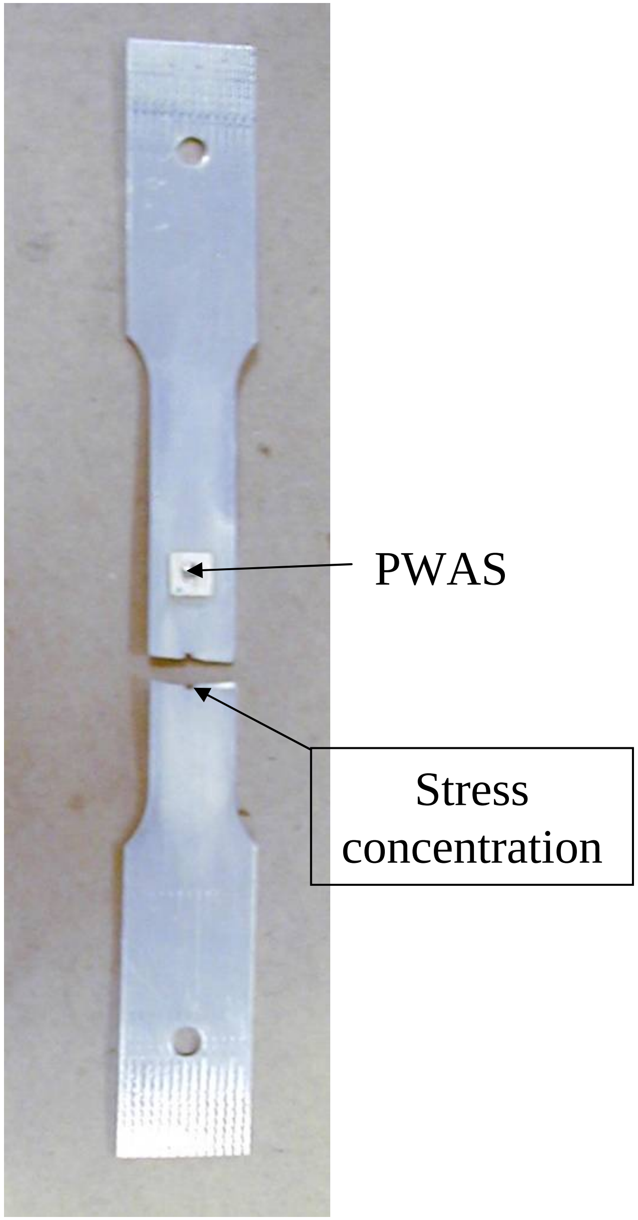


Failed PWAS @ 7300 με

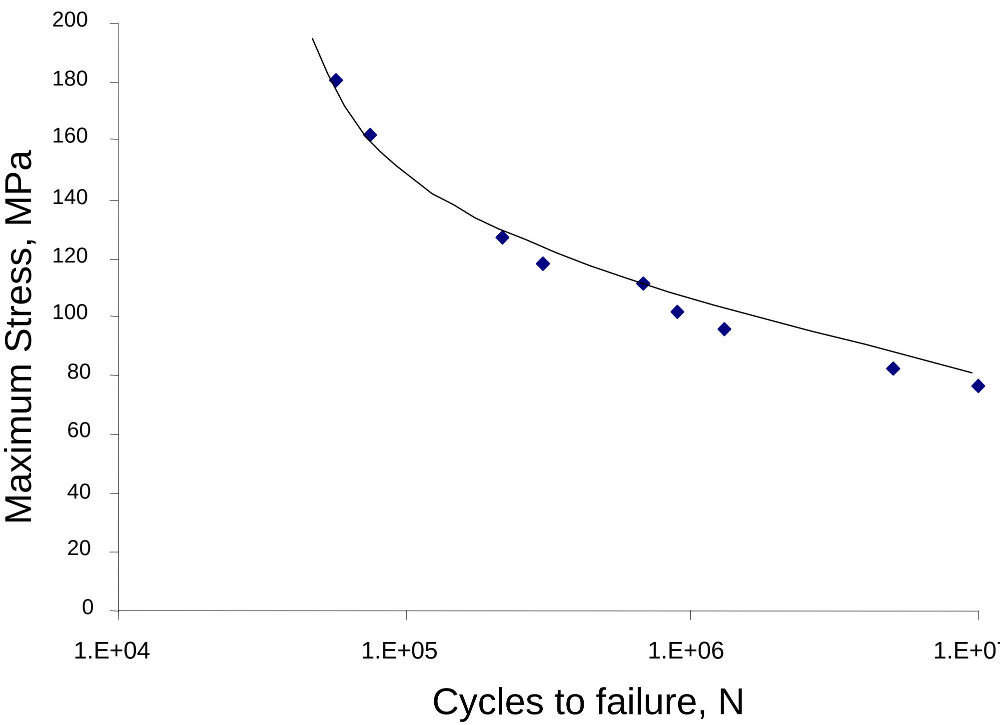
- Minimal changes up to 4000 με (0.84Y)
- Failure at 7300 με (1.13Y)



PWAS Fatigue Survivability Tests



	PWAS F1	PWAS F2	PWAS F3	PWAS F4	PWAS F5
Max load	2104 N	1560 N	1335 N	1156 N	1067 N
Min load	210 N	156 N	134 N	116 N	107 N
Mean load	1157 N	858 N	734 N	636 N	587 N
Cycles to failure	178 kc	670 kc	1.3 Mc	6.25 Mc	12.2 Mc



Conclusions

- Piezoelectric wafer active sensors (PWAS) are a promising technology for active structural health monitoring
- Durability and survivability of PWAS
  - Temperature cycling
  - Outdoor exposure
  - Submersion exposure
  - Large strains and fatigue loads
- Further work needs to be performed to better understand and gain confidence in this emerging technology

Thank you!