

# ORNL Capability for ARPA-E REPAIR

*Composite formulation, fabrication, and inspection*

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U.S. DEPARTMENT OF  
**ENERGY**

# ORNL Leads Major R&D Program

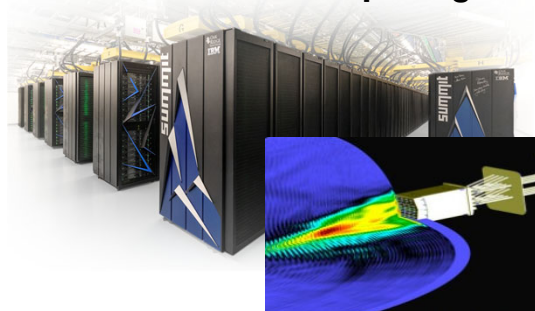
## ORNL Mission

Deliver scientific discoveries and technical breakthroughs needed to realize solutions in energy and national security and provide economic benefit to the nation

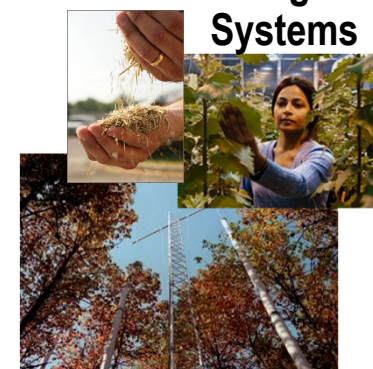
### Energy Technologies



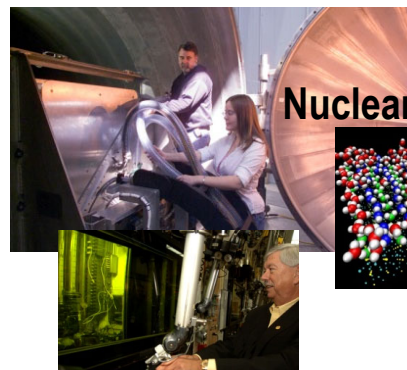
### Ultrascale Computing



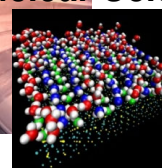
### Biological Systems



### Neutron Science



### Nuclear Science

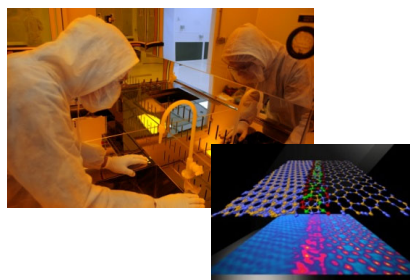


### Climate

### National security



### Advanced Materials





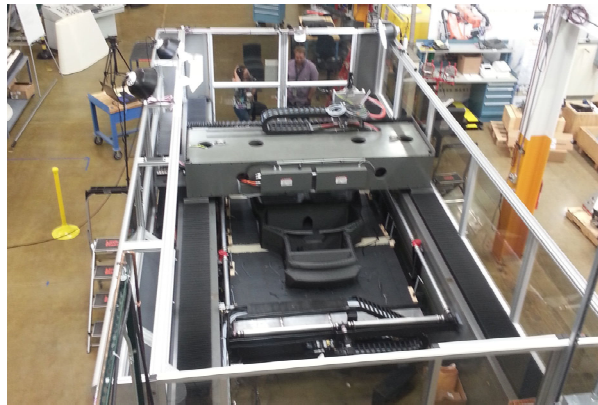
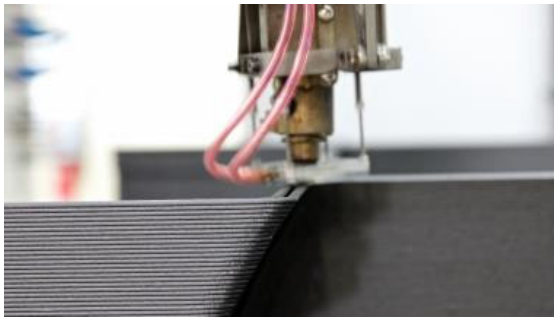
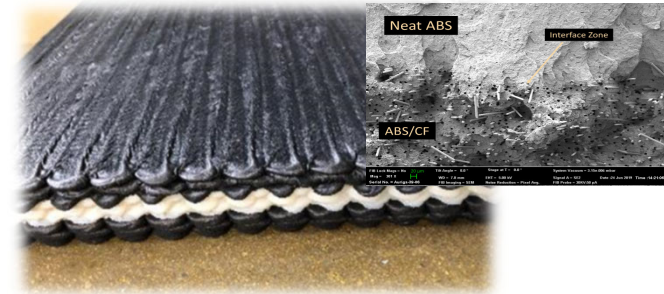
# Polymer Composite Printing at ORNL

- Knowhow in 3D printing of polymer composites should be applicable to coatings by an automated robotic

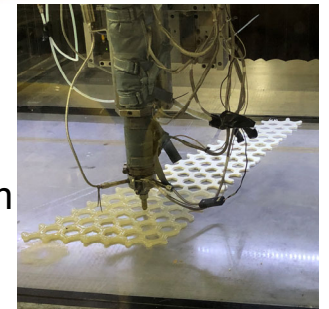
– Current Status:

- Fused Deposition Modeling
- Deposition of multiple polymers (foams, engineered material, composites)
- Pick and place of sensors

ABS and ABS + Carbon Fiber



PLA to PLA Foam

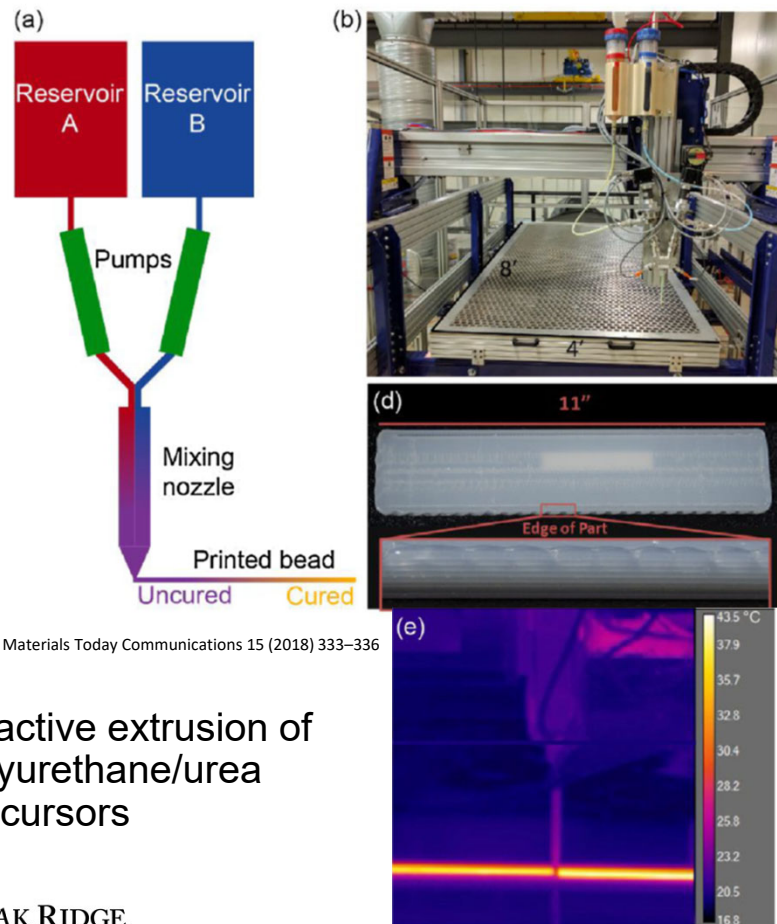


[www.ornl.gov/manufacturing](http://www.ornl.gov/manufacturing)

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# Coextrusion of Curable Prepolymers and a Long History of Polymer Composite Formulation

## Carbon Fiber Technology Facility

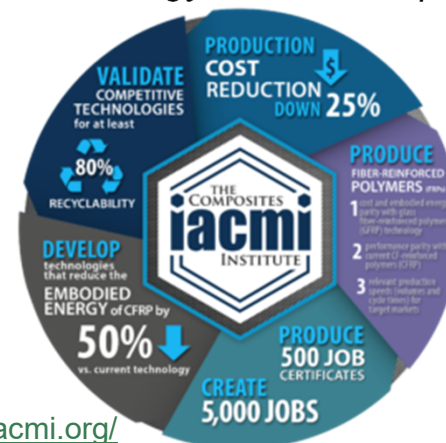


Rios et al. Materials Today Communications 15 (2018) 333–336

Reactive extrusion of  
polyurethane/urea  
precursors



*A national asset to assist industry in lowering carbon fiber cost, scaling technology, and developing products and markets*



<https://iacmi.org/>

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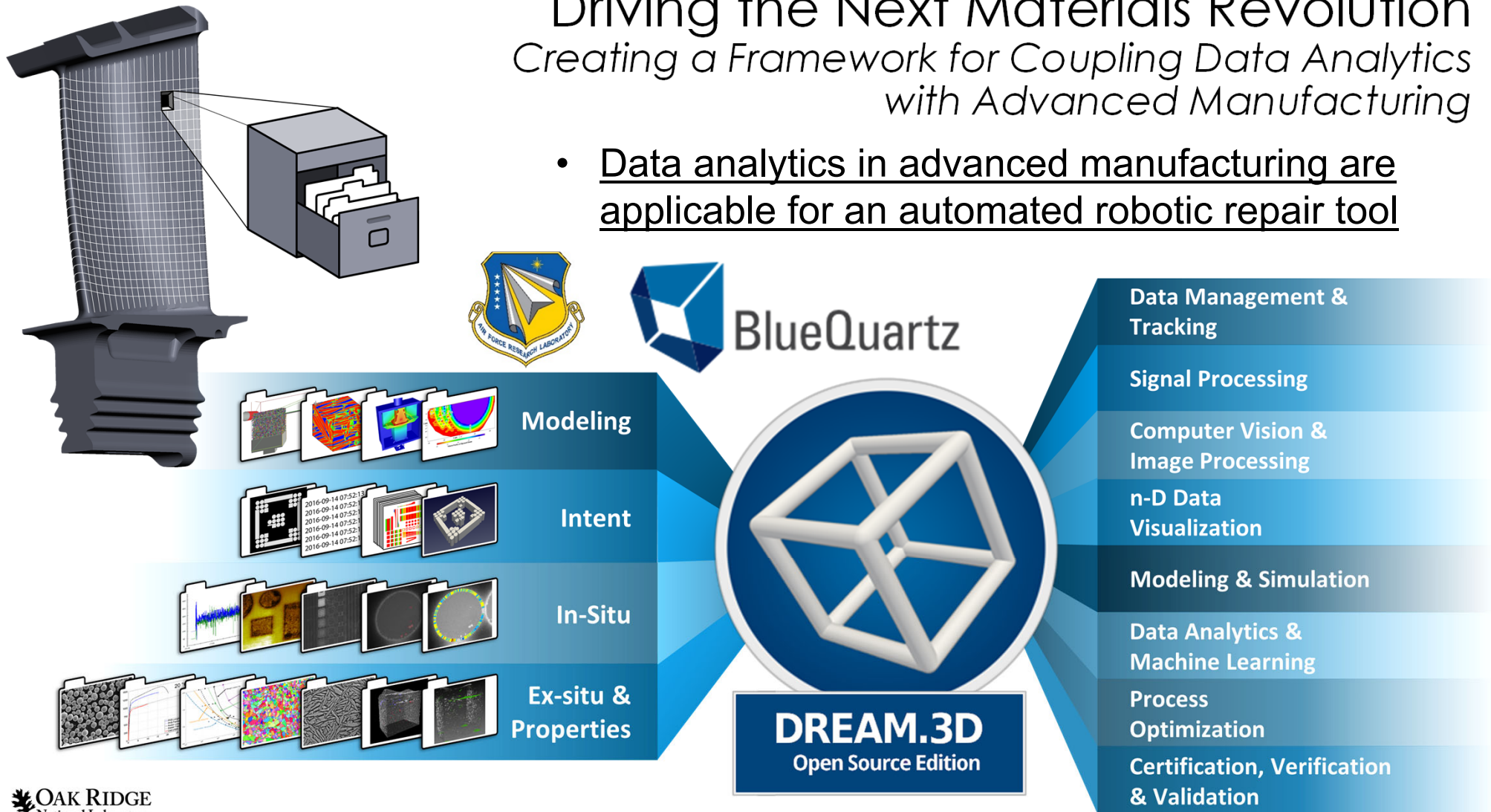




# Driving the Next Materials Revolution

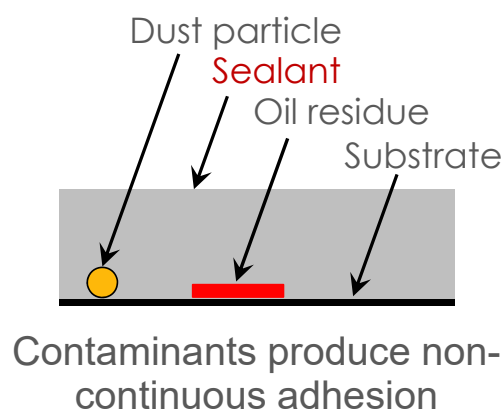
## *Creating a Framework for Coupling Data Analytics with Advanced Manufacturing*

- Data analytics in advanced manufacturing are applicable for an automated robotic repair tool

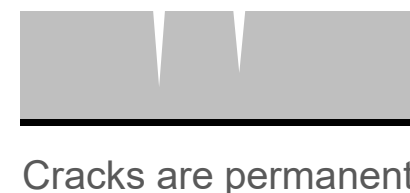
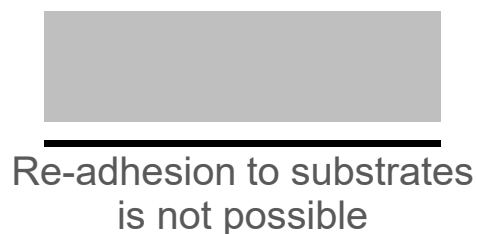


# Primer-less Self-healing Sealants/Adhesives

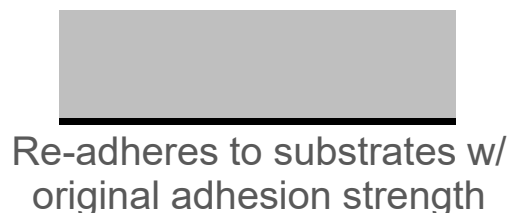
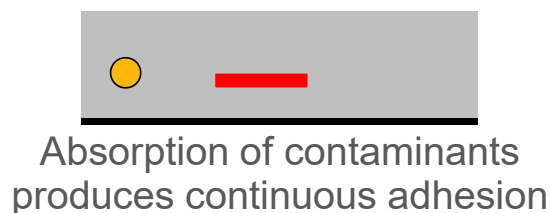
- Self-healable coating will provide longevity
- Coating without surface preparation needs to be carefully designed



## Conventional Sealants



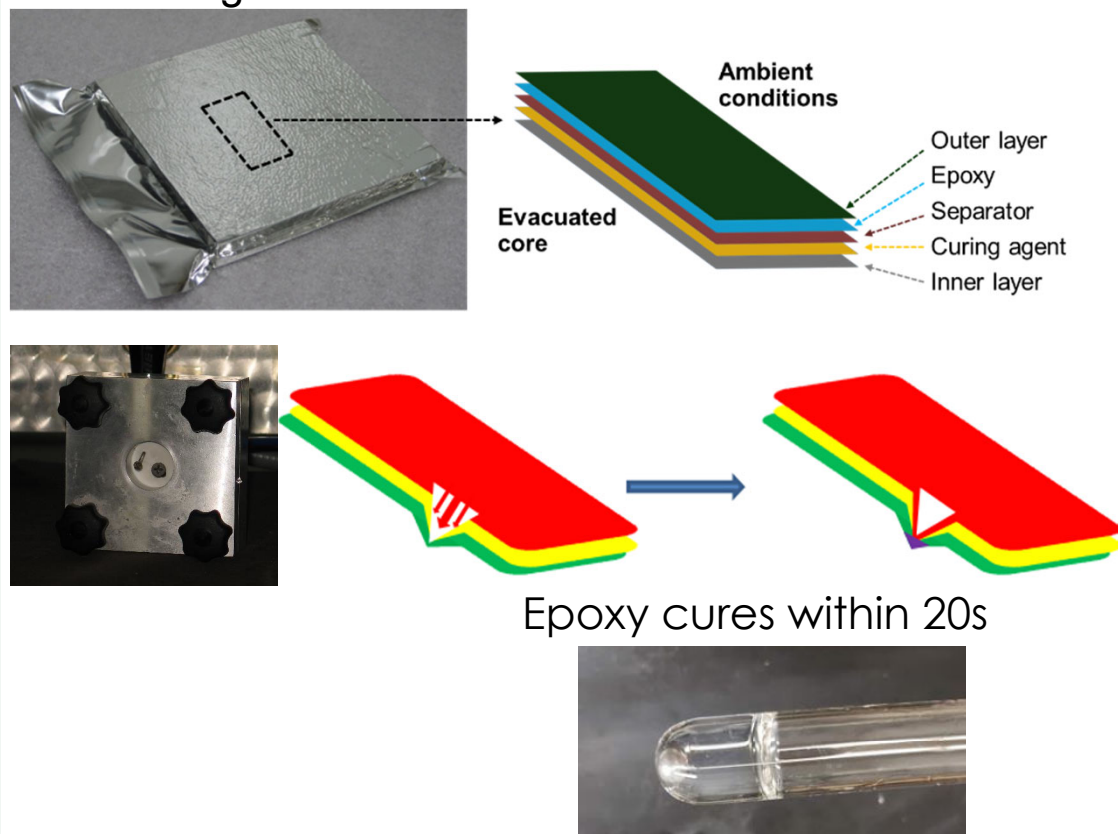
## ORNL's Self-healing Sealant



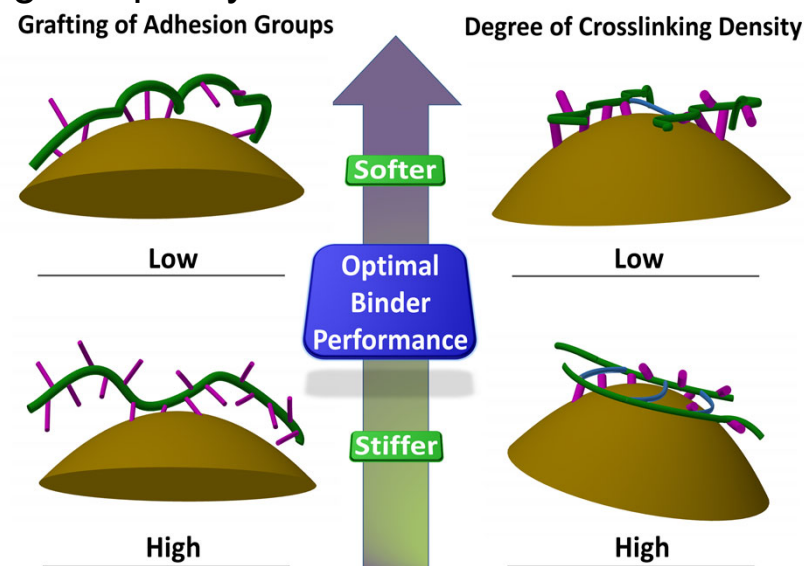
# Fast Curing Epoxy and Control Parameters for Adhesion

- Minimal curing and robust coating formulation will be needed

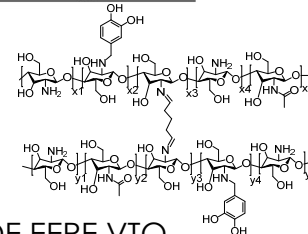
## Self-healing Barrier Film for Vacuum Insulation Panel



## Rational Design of a Multifunctional Binder for High-Capacity Silicon-Based Anodes



The importance of balancing catechol groups and degree of crosslinking was identified

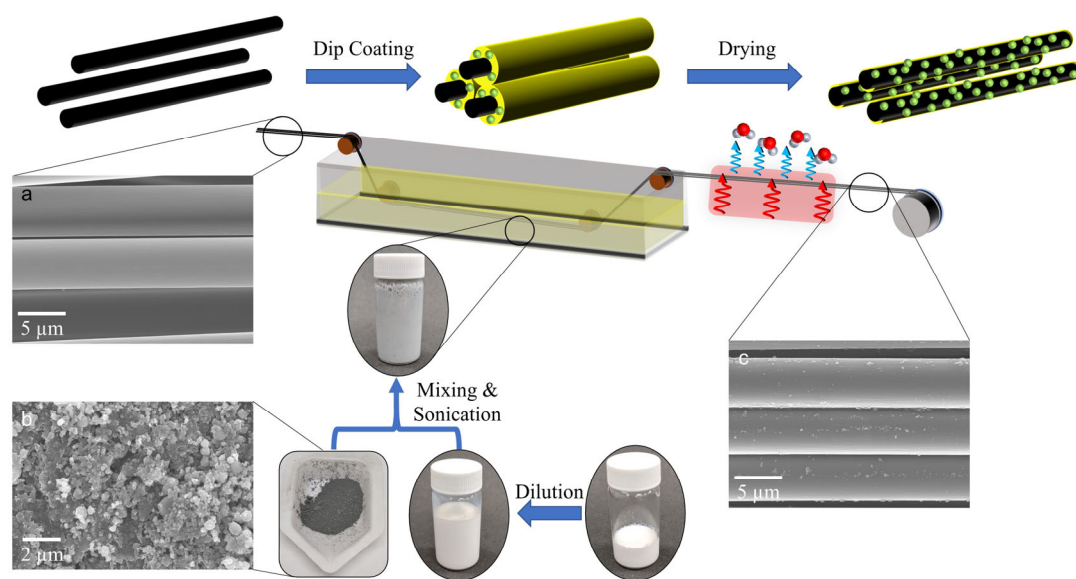


ACS Energy Lett. 2019, 4, 1171–1180 DOE EERE VTO

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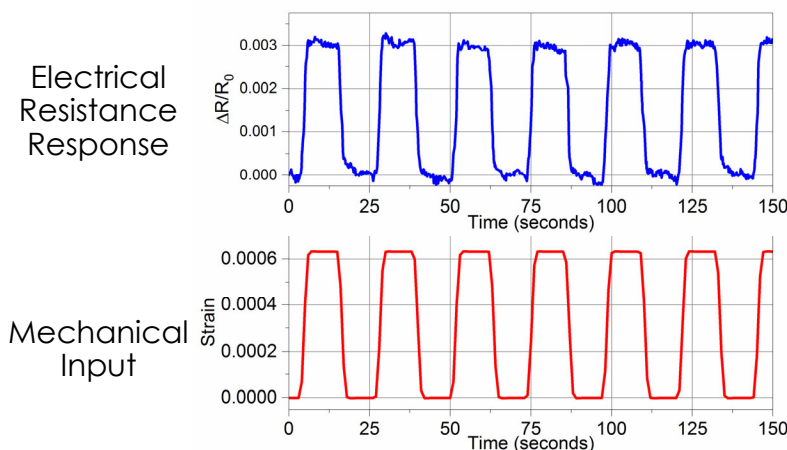
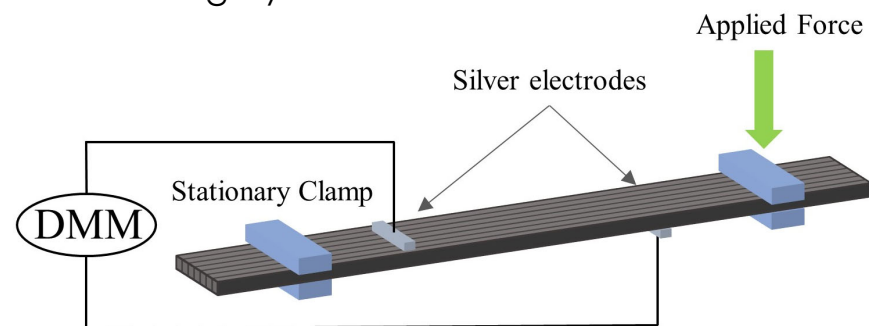
# Next Generation Self-Sensing Multifunctional Composites via Embedded Nanomaterials

- Self-sensing composites could be used to detect failures in pipes



Method to integrate ceramic nanoparticles into composites

Out-of-plane through thickness variation of composite resistivity was monitored during dynamic mechanical forces



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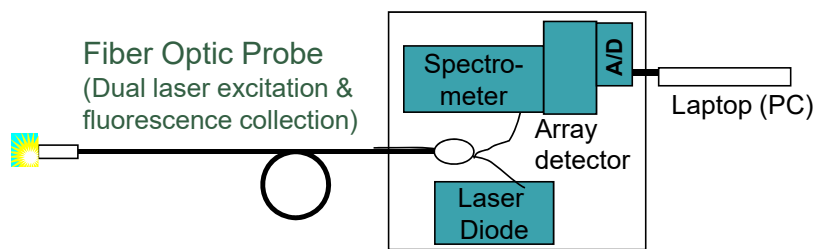
Bowland et al. *ACS Applied Materials & Interfaces* 10 (31), 26576 (2018).



# Laser Induced Fluorescence-Based Nondestructive Evaluation of Heat Damaged Composite Aircraft

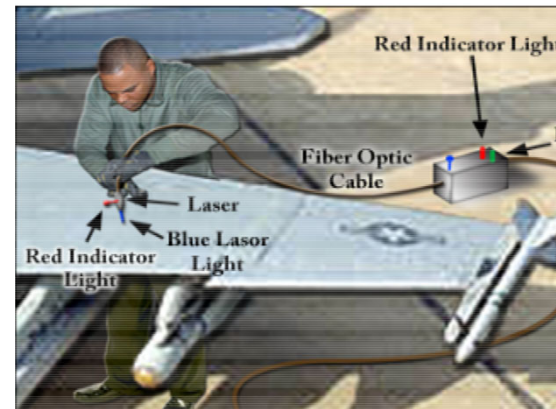
- Laser Induced Fluorescence can detect defects

Portable (Point Source) LIF NDE Unit



Correlation Curve data inputted to NDE software as Damage Threshold level for specific composite material

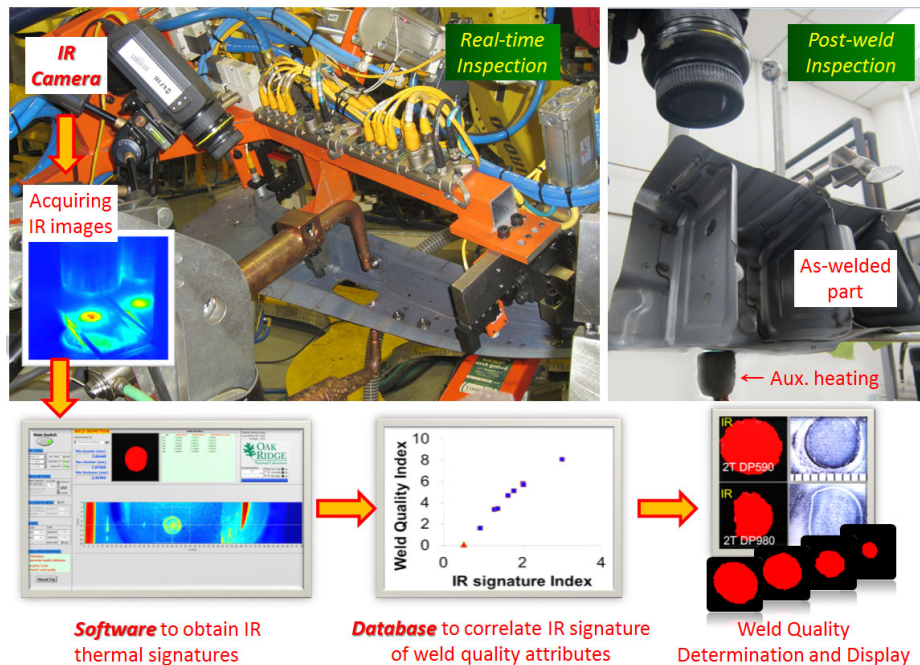
- 2008 R&D100 Award
- Carbon fiber /epoxy based composite structures experience delaminations, disbonds, cracking and surface blistering at temperatures beyond 550°F
- Acoustic based NDE techniques can detect these types of damage
- Heat damaged polymer matrices exhibit changes to their laser induced fluorescence spectra over a range of time/temperature expose conditions including those defined as incipient damage



After paint removal, operator inspects fire damaged area to assess extent of exposure; area size determines repair or part replacement

# Infrared Nondestructive Weld Examination System

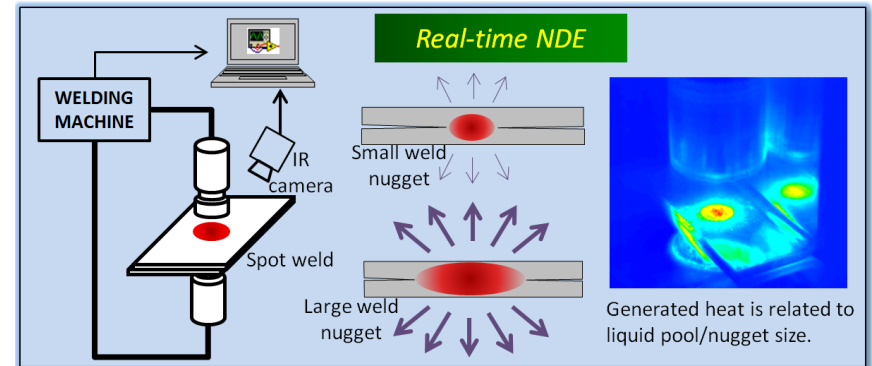
- Infrared and Acoustic nondestructive inspection tools used for welding can be used for pipes
- Technology
  - Capable for both real-time online and post-weld NDE
  - Suitable to high-volume mass production environment
- 2015 R&D100 Award



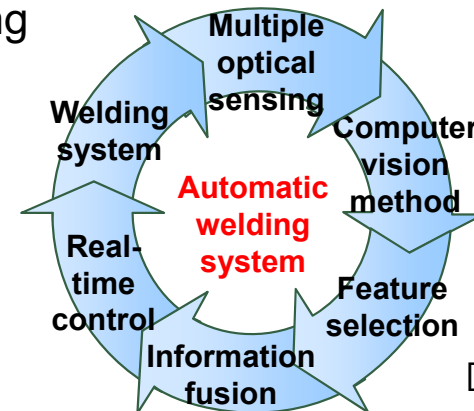
Software to obtain IR thermal signatures

Database to correlate IR signature of weld quality attributes

Weld Quality Determination and Display



On-going: Real time control of welding process based on AI and machine learning



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# Conclusions and Outlook

- Many technologies in advanced manufacturing coupled with data analytics are applicable for automated robotic repair tool
- Advanced composite coating with no surface preparation, minimal curing time, robust mechanical properties and tailored processability along with self-healing and self-healing is possible
- Inspection tool with data analytics (machine learning etc.) developed for other technologies including inspecting welding (Infrared, acoustic) and composite (laser) is applicable for the development for the inspection tool in REPAIR

Thank you for your attention!

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