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# Composite Thermal Damage Measurement with Handheld FTIR

April 9, 2013

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# Composite Thermal Damage Measurement with Handheld FTIR

- Motivation and Key Issues
  - Damage detection in composites requires different techniques than metals
  - Incipient thermal damage occurs below traditional NDE detection limits
- Objective
  - Determine if handheld FTIR can detect thermal damage and guide repair
- Approach
  - Characterize panels with controlled thermal damage and perform repair based on FTIR inspection

# FAA Sponsored Project Information

- Principal Investigators & Researchers
  - Brian Flinn (PI)
  - Ashley Tracey (PhD student, UW-MSE)
  - Tucker Howie (PhD student, UW-MSE
- FAA Technical Monitor
  - David Galella (year 3)
  - Paul Swindell (year 1 & 2)
- Industry Participation
  - The Boeing Company (Paul Shelley, Paul Vahey)
  - Sandia National Lab (Dennis Roach)
  - Agilent (formerly A2 Technologies)

# Background

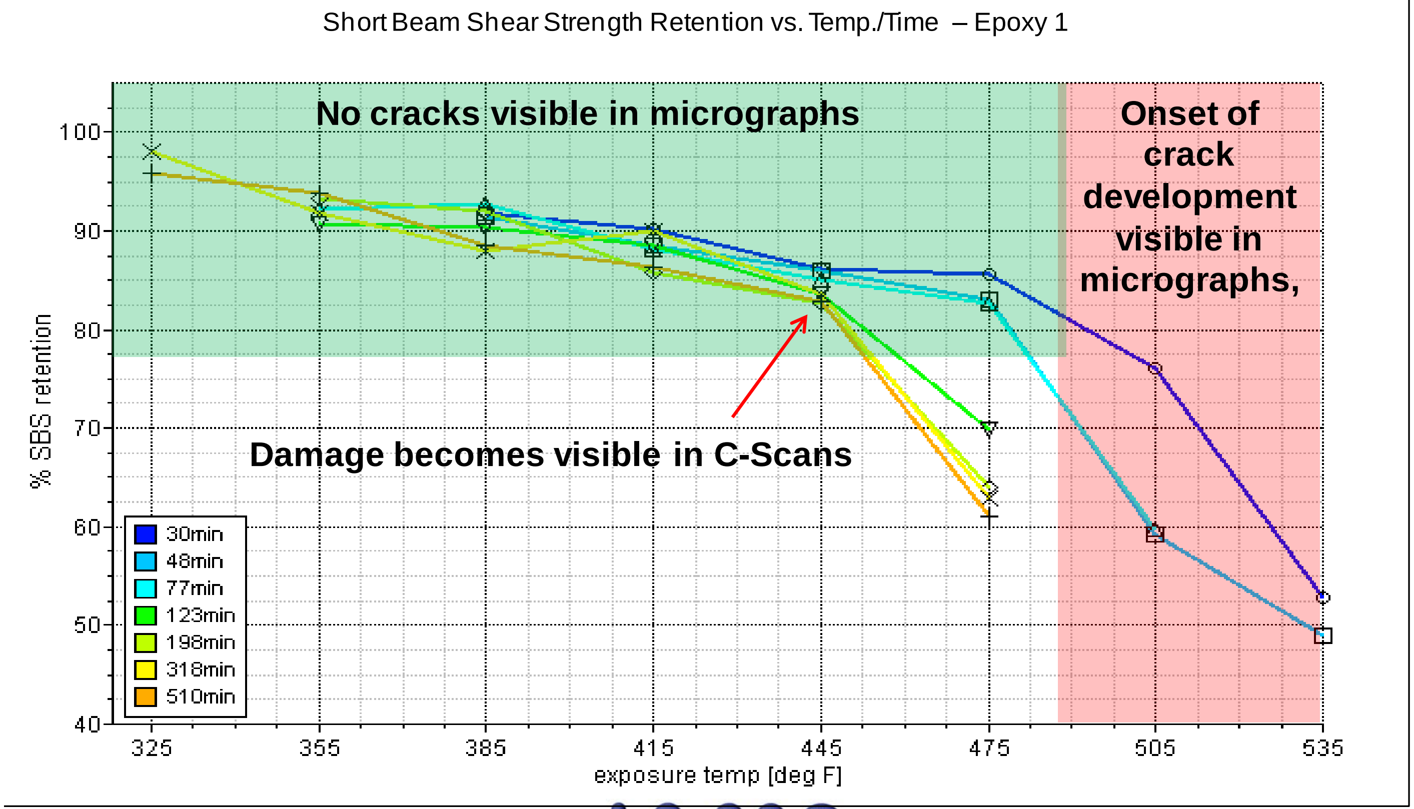
Continuation of existing project (year 3 of 3)

✓ Years 1 and 2 (A2 Technologies, Boeing and U of DE)
  - Characterization of homogeneous thermal damage
    - Ultrasound
    - Short beam shear (SBS)
    - Microscopy
    - Handheld FTIR (ExoScan)
  - Calibration curve for FTIR detection of thermal damage (SBS data)
  - Mapped surface of localized thermal damage

➢ Year 3 (UW and Boeing)
  - 3-D characterization of localized thermal damage
  - Include contact angle and fluorescence spectroscopy
  - FTIR guided repair of thermal damage
  - Test repair

# Thermal Damage vs. Detection Method

- SBS, ultrasound, and microscopic analysis of composites with thermal damage
  - Properties degrade before detection possible → need method to detect incipient thermal damage (ITD)



# Experimental Overview

**Investigate ITD of composites with various inspection techniques**

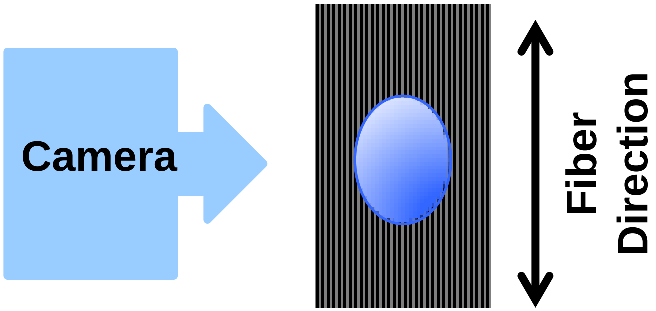
- Characterize composite samples and panels with controlled thermal damage using various methods:
  - Contact angle (CA)
  - Fluorescence
  - FTIR
- Can results be related to SBS values and detect thermal damage?

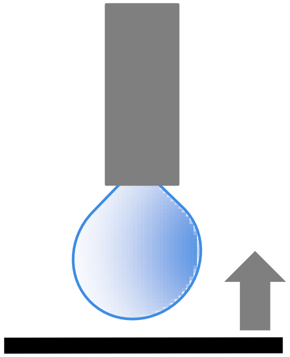
# Materials and Process

- Toray 3900/T800 composites with various levels of thermal damage
  - Provided from Year 1 & 2 research
  - SBS samples thermally exposed in air
  - Panels with localized thermal damage in vacuum
- Characterize toolside (resin rich) and sanded (resin poor) surfaces
  - Sand surfaces with random orbital sander using 120 grit 3M $Al_2O_3$ sanding pads
- Measurement techniques: CA, fluorescence, FTIR

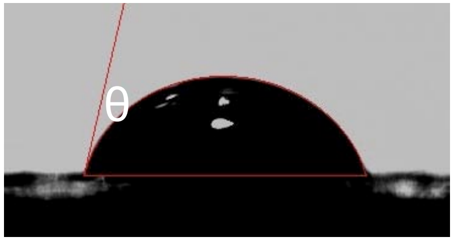
# Materials and Process – Contact Angle

- Measure CAs of 1 μL sessile drops from side view
  - 5 drops (10 CAs) per fluid
- Fluids: DI water, diiodomethane (DIM)
- Measure at 0 degrees with respect to fiber orientation



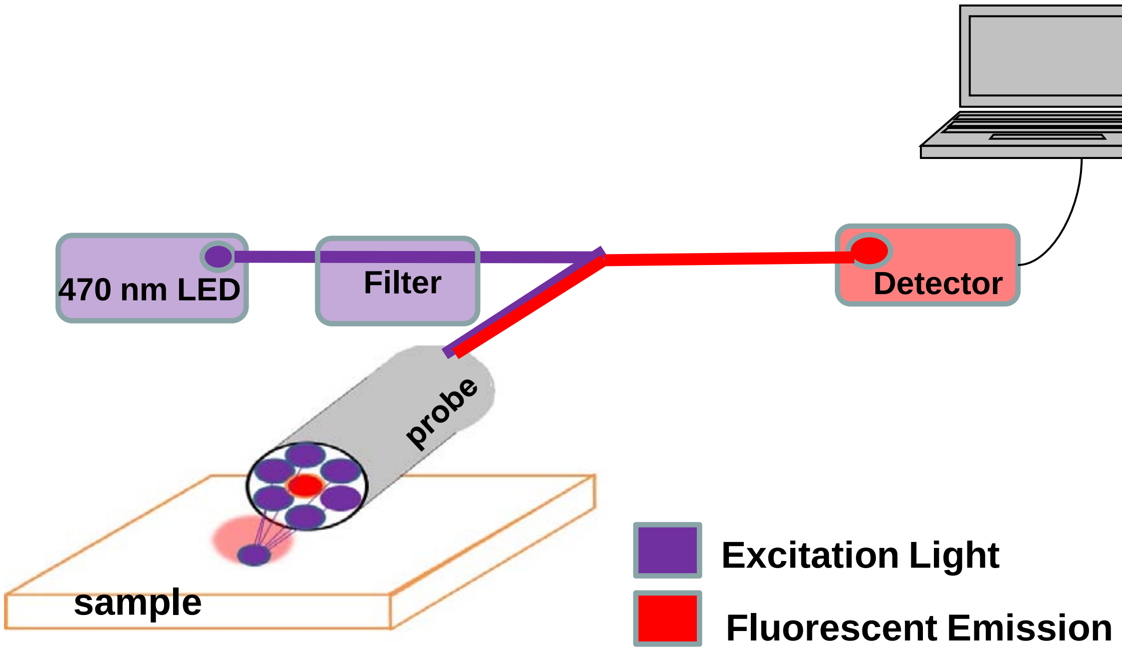



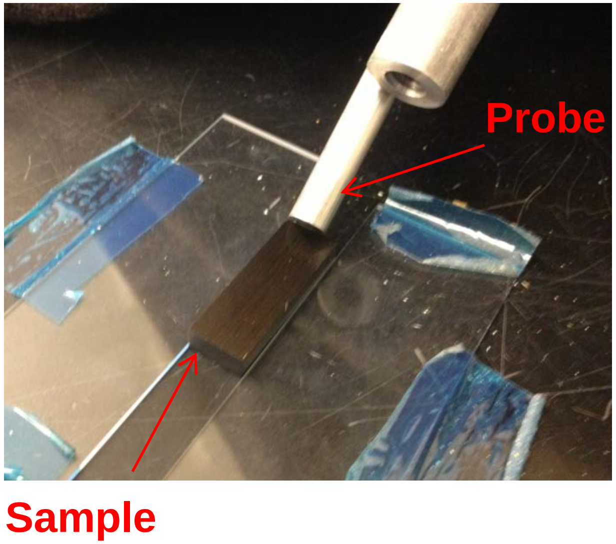
Drop application: dispense drop, raise surface




Side-view of drop as viewed from goniometer camera

# Materials and Process – Fluorescence



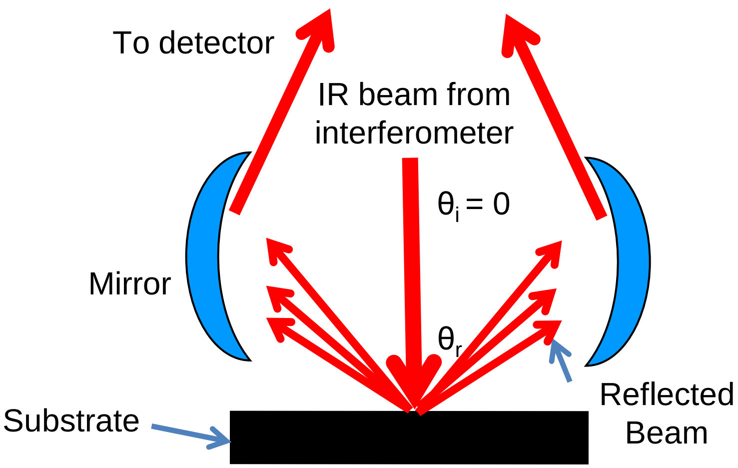




- Sample absorbs excitation light and emits light at longer wavelength than the absorbed light (fluorescence).
- Measure changes in intensity and wavelength at max intensity ($\lambda_{MAX}$) of fluorescence emission

# Materials and Process – FTIR

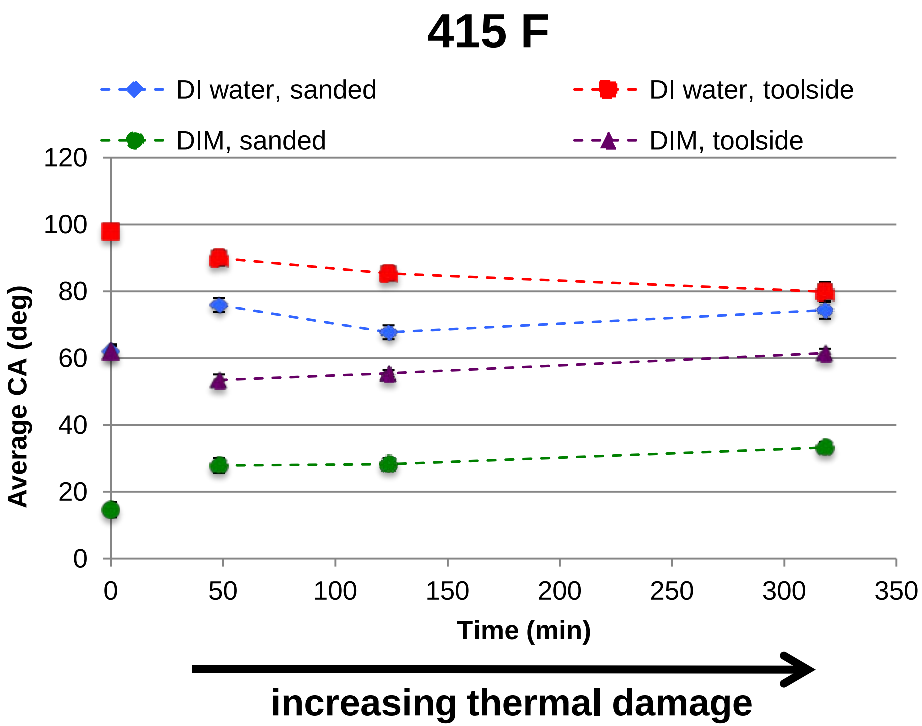
- Mid-IR data region: 4000 $cm^{-1}$ to 650 $cm^{-1}$
- Diffuse reflectance sampling interface
- Data collection: 120 coadded scans with 8 $cm^{-1}$ resolution for background and specimen

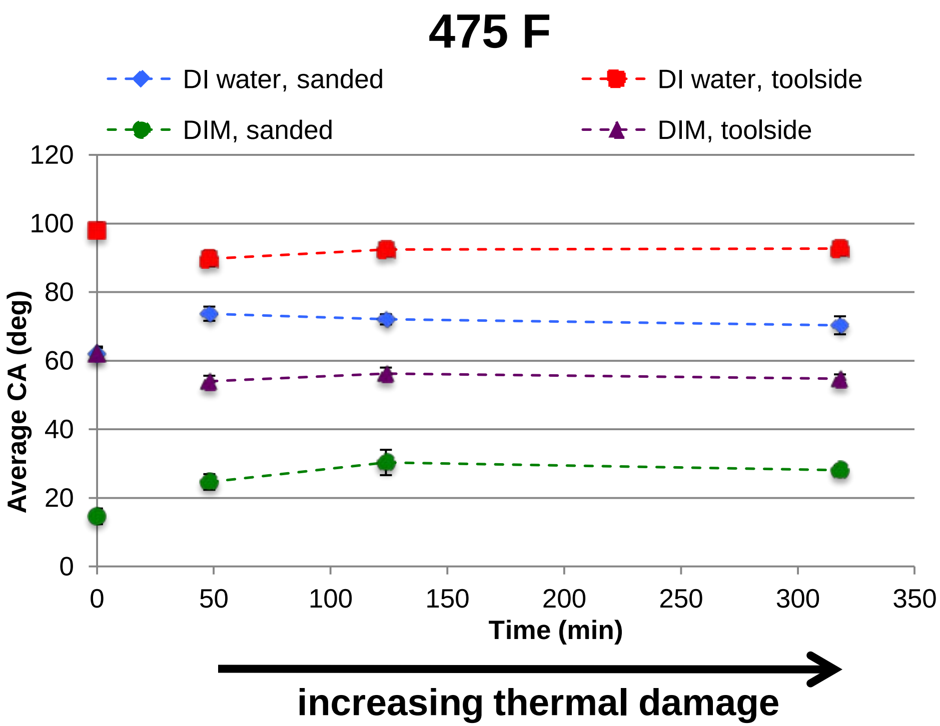
**ExoScan FTIR**




**An infrared beam path for diffuse reflectance**

# Year 3 Results: CA Measurements on SBS Samples




- CA on sanded surface lower than toolside surface
- No significant correlation between SBS values and CA measurement – 415, 445, 475, 505 °F

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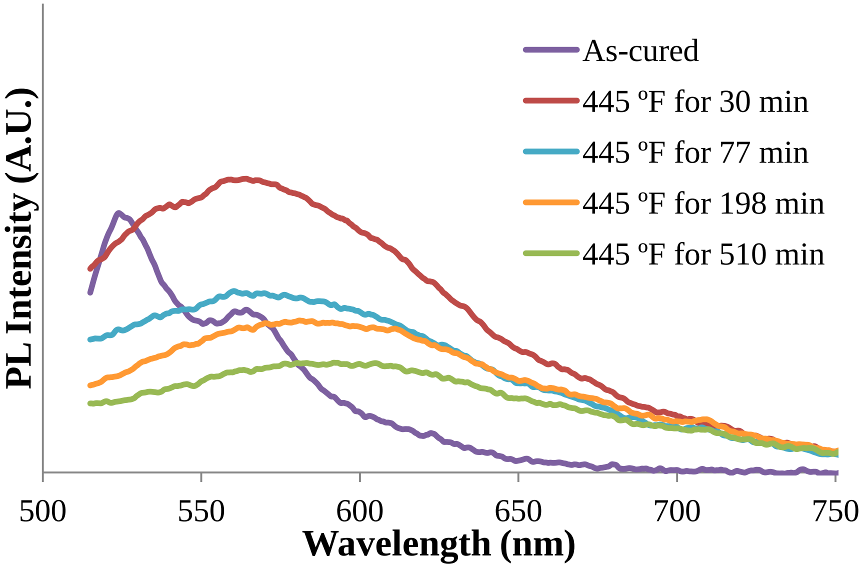
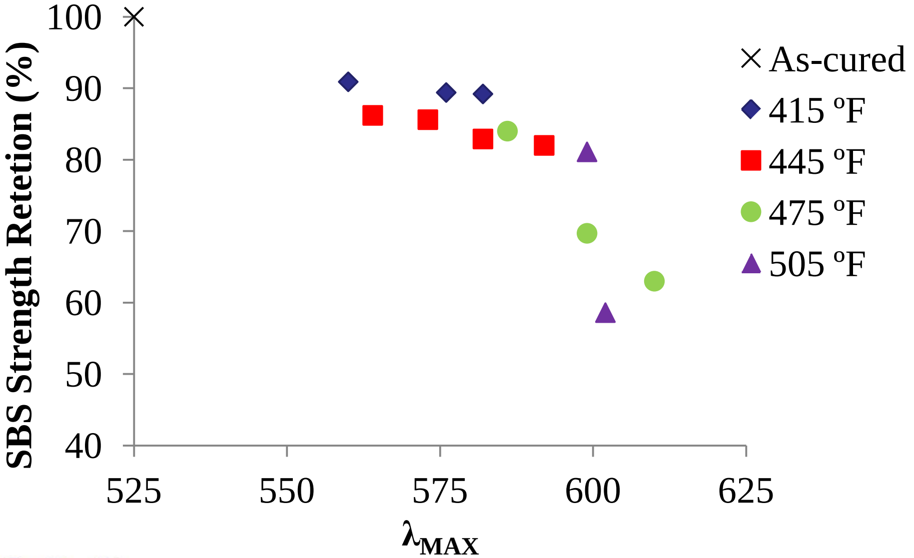
# Year 3 Results: Fluorescence of SBS Samples

- $\lambda_{MAX}$ red-shifts and intensity decreases with increasing exposure
  - $\lambda_{MAX}$ does not monotonically relate to SBS retention
- No fluorescence measurable on sanded surface

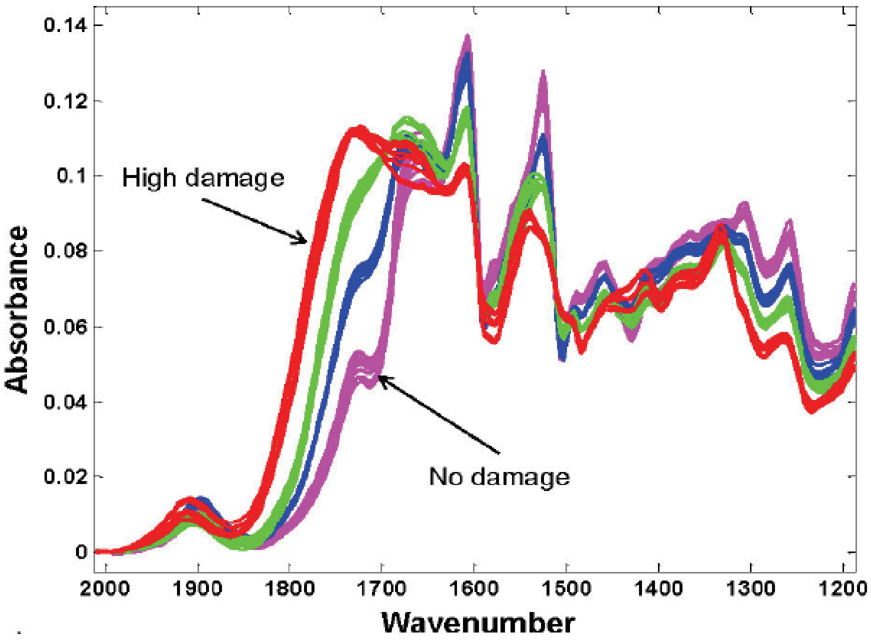


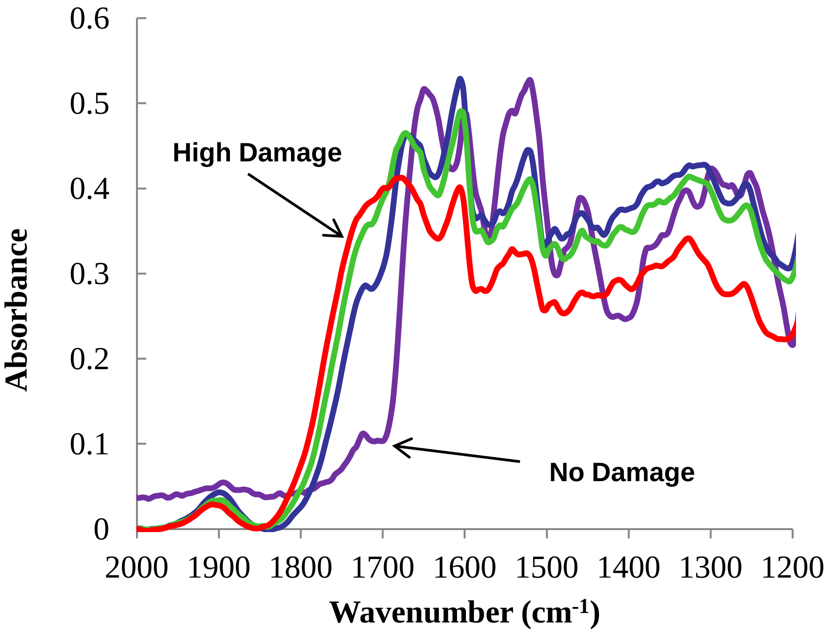
# Year 3 Results: FTIR Verification

- FTIR measurements on resin rich surface of SBS consistent with previous results
  - Oxidation peaks increase with damage

**Year 1 & 2**

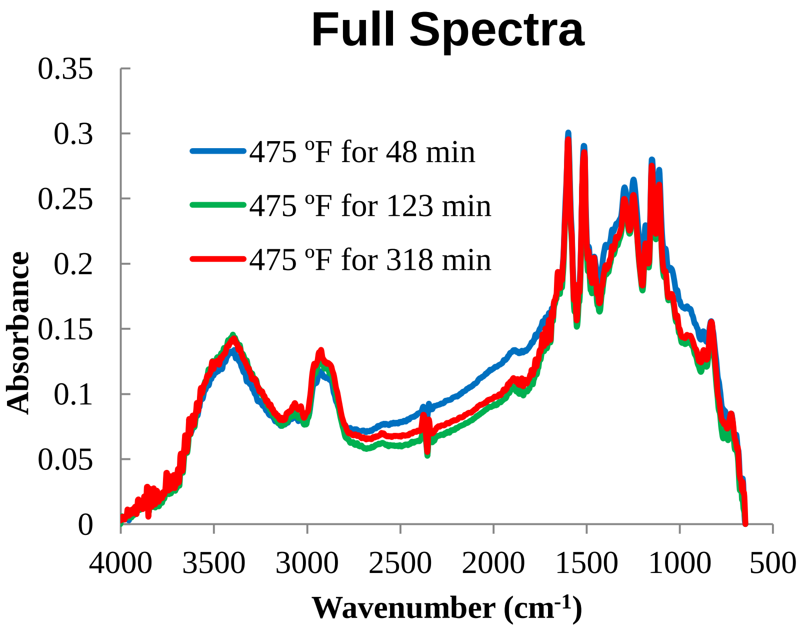


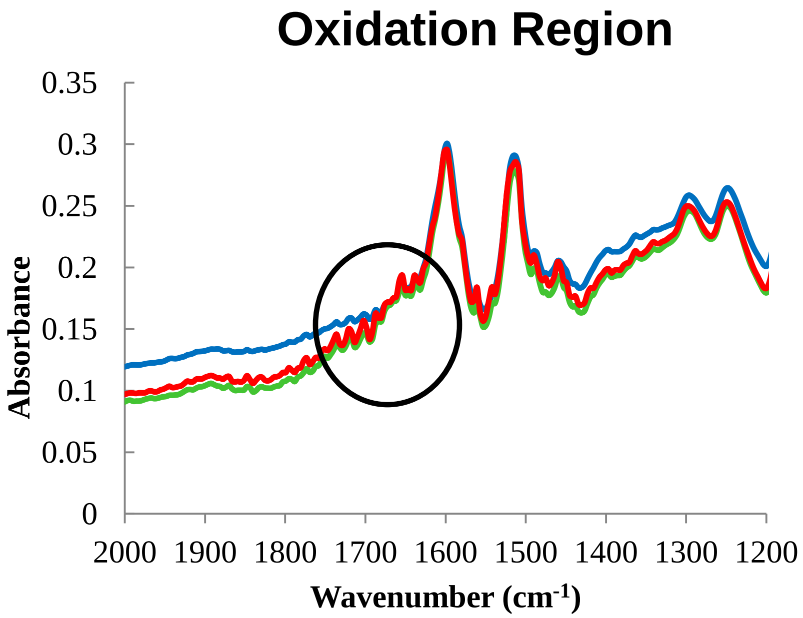

**Year 3**



# Year 3 Results: FTIR on Sanded Surfaces

- Damage is not as clear as on toolside surface
  - – Oxidation removed by sanding
    - ➢ Need multivariate analysis to determine differences in spectra and correlate to SBS data

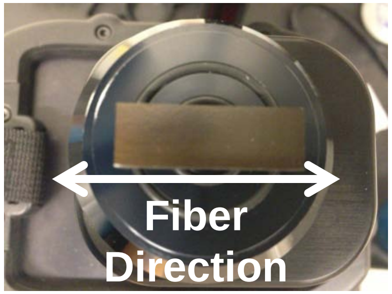


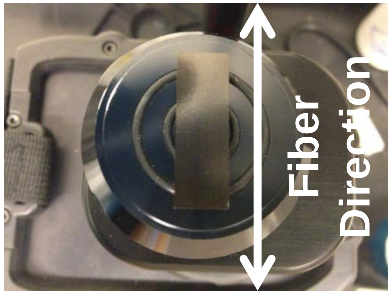
# Year 3 Results: FTIR Orientation

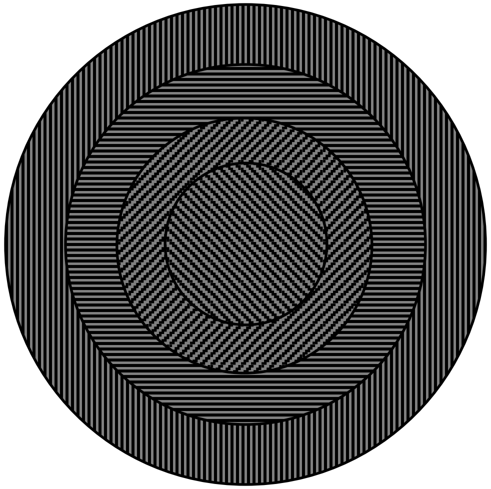
- Signal varies based on sample orientation
  - FTIR needs to be rotated during repair to match fiber orientation

**0 º orientation**

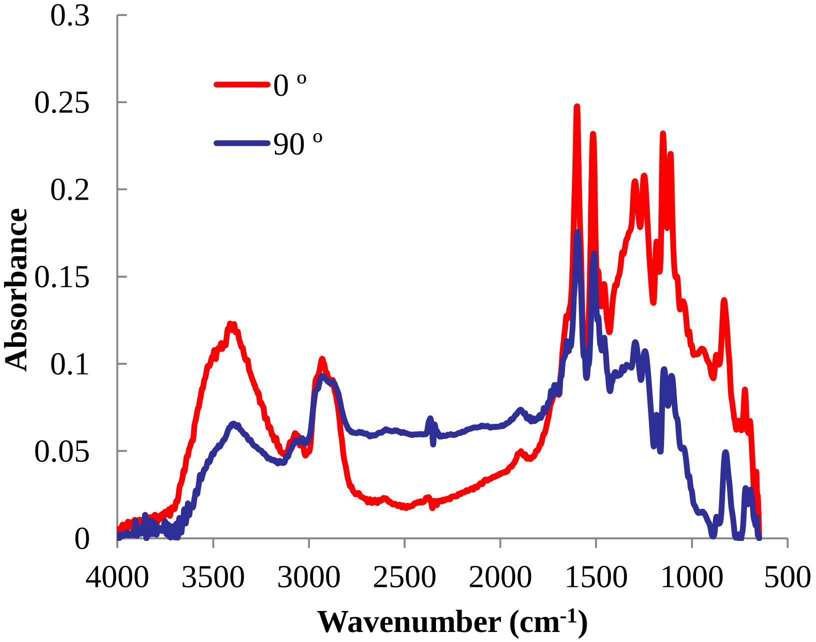



**90 º orientation**



**Top down schematic of scarfed surface showing how fiber orientation changes at each layer**

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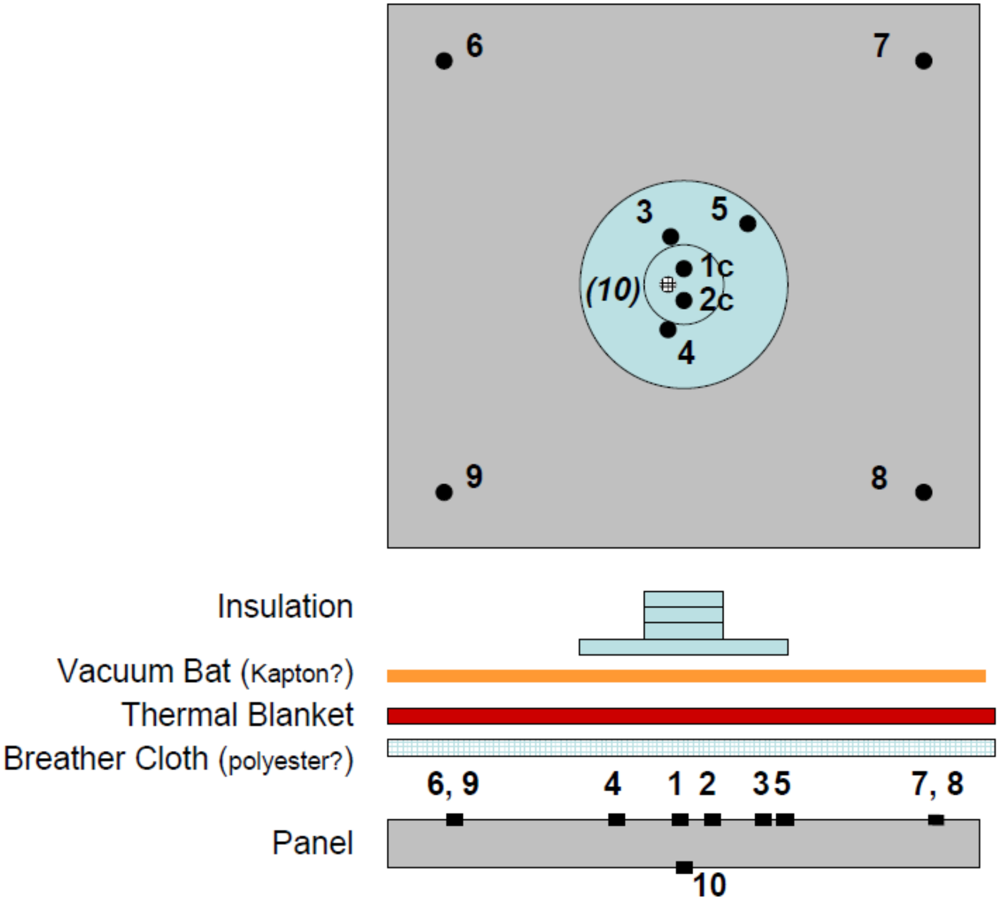
# Year 1 & 2 Results: Localized Damage

- Hot spots created
- 3 temperatures
  - 440, 465, 490 °F
- 2 panels each

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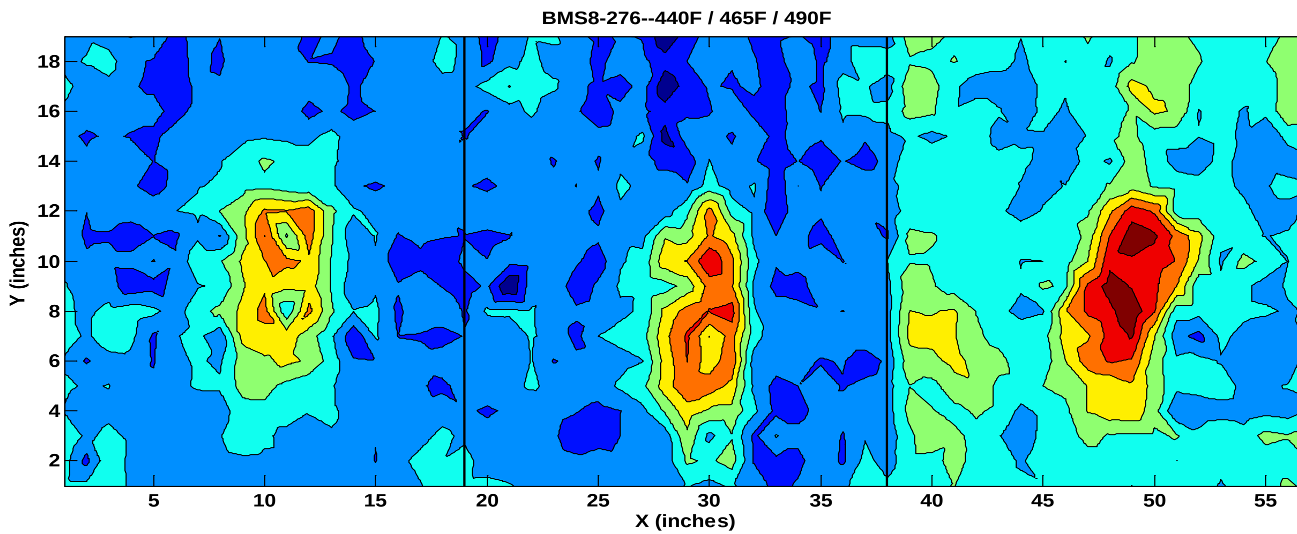
# Year 1 & 2 Results: Map of Localized Damage

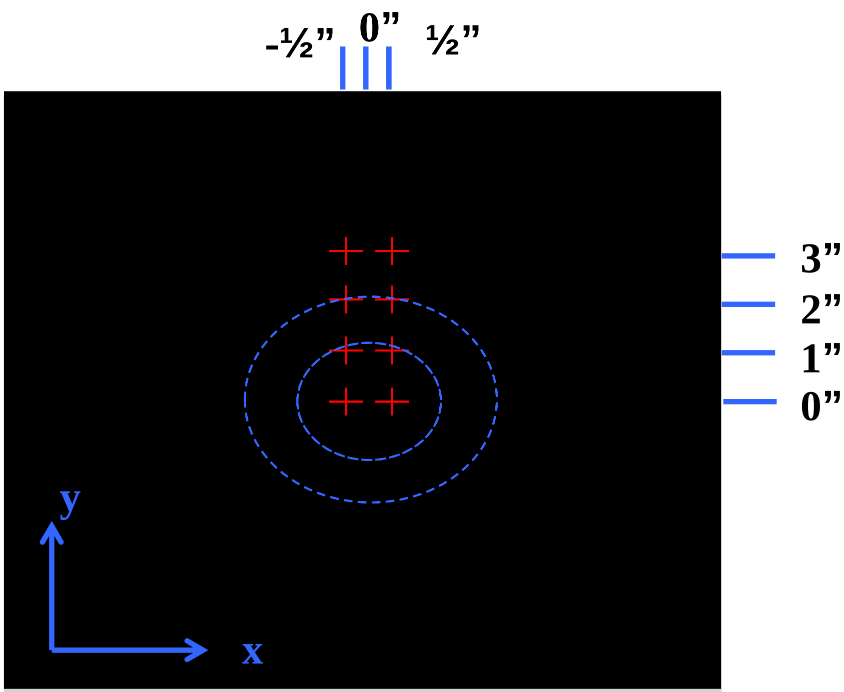
- FTIR Map of Surface Damage
  - Blue is low damage
  - Brown is high damage

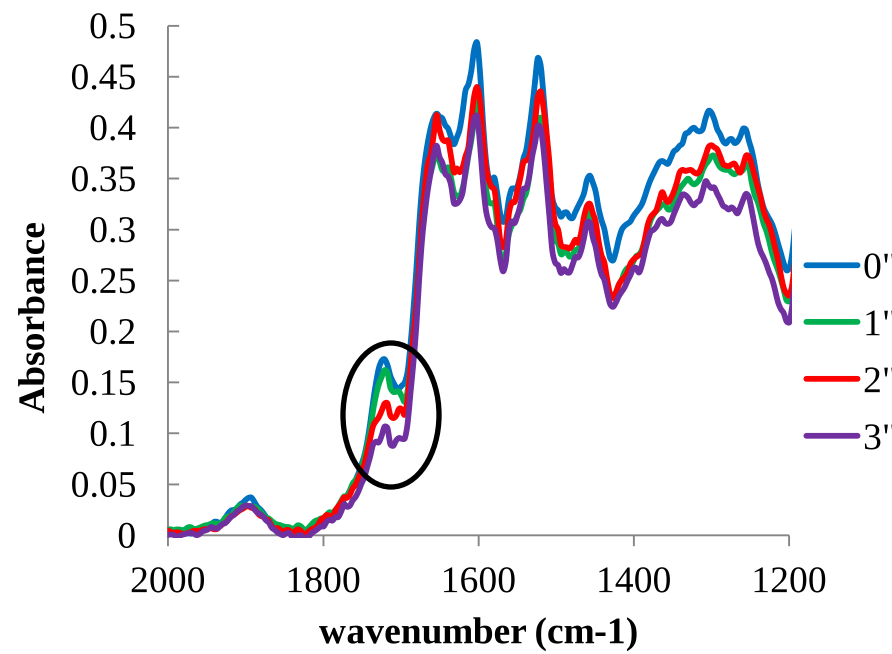



**Low (440 ºF for 1 hr)**  **Medium (465 ºF for 1 hr)**  **High (490 ºF for 1 hr)**

# Year 3 Results: Panel Mapping

- Preliminary measurements performed
- FTIR spectra different than resin rich surface of SBS samples
  - Panels heated in vacuum → less oxidation
  - Changes in oxidation peaks at 1720 $cm^{-1}$ still observed
    - Oxidation peak decreases as distance from center increases



# Summary

- Preliminary results generated
  - No clear correlation of ITD with contact angle
  - No clear correlation of ITD with fluorescence
  - Oxidation detected on resin rich surfaces
  - Resin poor surfaces require advanced analysis techniques
- Ready to proceed to next stage
  - Multivariate analysis of resin poor surfaces
  - 3-D panel mapping

# Future Work

- Apply multivariate analysis
- Surface map thermal damage (all panels)
- 1st set of panels- mechanical testing (SBS, Tg)
- 2nd set of panels – scarf repair guided by FTIR
  - Map damage ply by ply during scarfing FTIR
  - Correlate FTIR measurements to mechanical tests to guide repair
  - Bonded repair followed by NDE
  - Mechanical testing of repaired panel

# Looking Forward

- Benefit to Aviation
  - Improved damage detection
  - Greater confidence in repairs
- Future needs
  - Application to other composite systems
  - Other applications of handheld FTIR
    - Chemical damage
    - Surface prep for bonding

# End of Presentation.

# Thank you.

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