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Advanced Materials in Transport Aircraft Structures

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Composite Thermal Damage Measurement with Handheld FTIR

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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

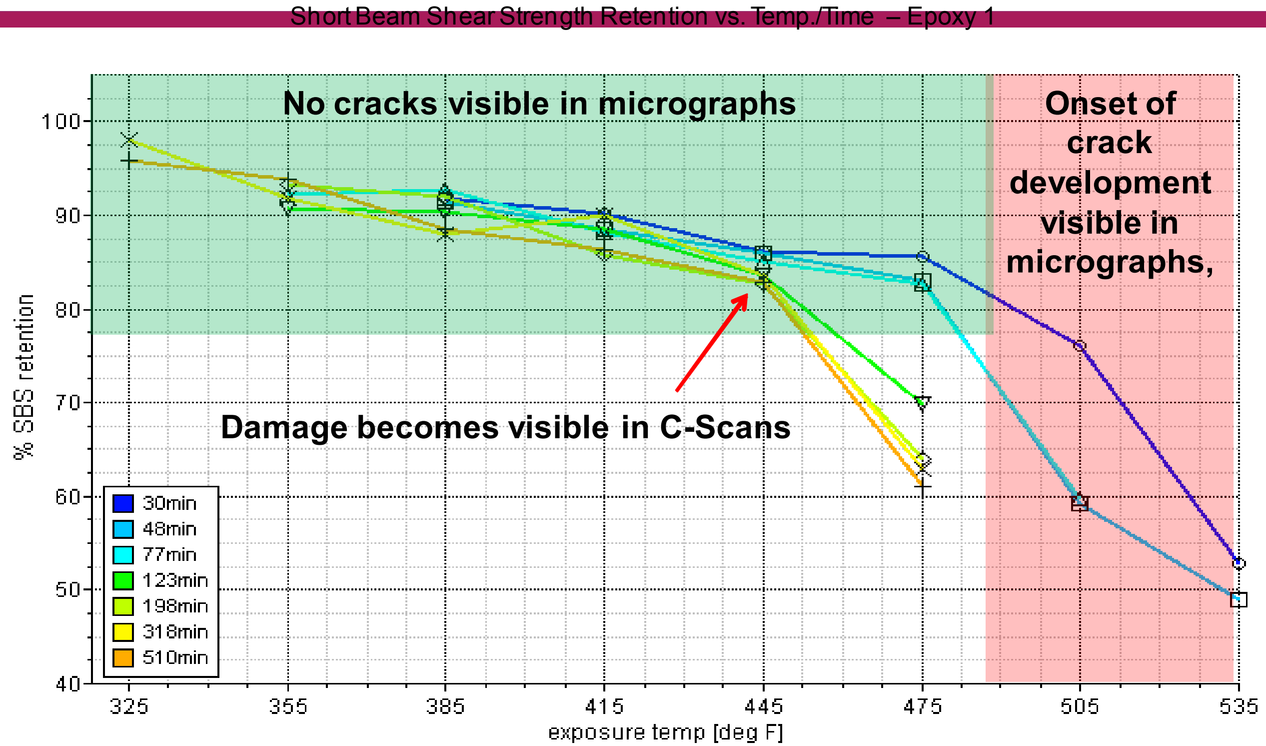
FAA Sponsored Project Information

- 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
  - Contact angle and fluorescence spectroscopy
  - FTIR guided scarf repair
  - Test repair

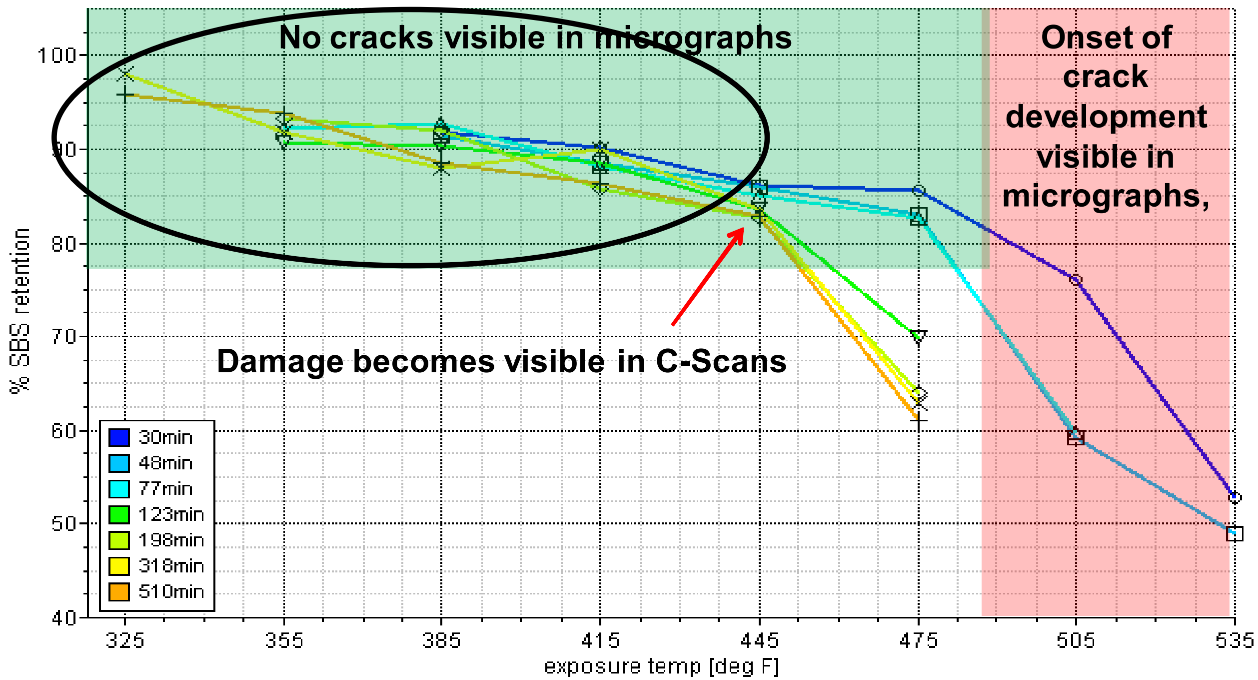
Thermal Damage vs. Detection Method



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

Thermal Damage vs. Detection Method

Short Beam Shear Strength Retention vs. Temp./Time – Epoxy 1



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Summary of Work Completed

	FTIR	Contact Angle	Fluor-escence
Thermal Damage	✔	✗	✗
Resin rich (tooled) surface	oxidation peaks characterized		
Fiber rich (sanded) surface	oxidation peaks absent → multivariate analysis (MVA)		
Fiber orientation	signal varies with orientation		
Surface finish	can only compare surfaces with MVA when surface finish is same		

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Experimental Overview

- Thermally Damaged SBS samples
- FTIR measurements on SBS samples
- Develop calibration curve for FTIR from SBS values
- Predict evaluation set to validate model
- Composite panel locally damaged
- Panel Mapped using FTIR
- Panel cut up for mechanical testing
  - SBS
  - Tg (DMA)

Materials and Process

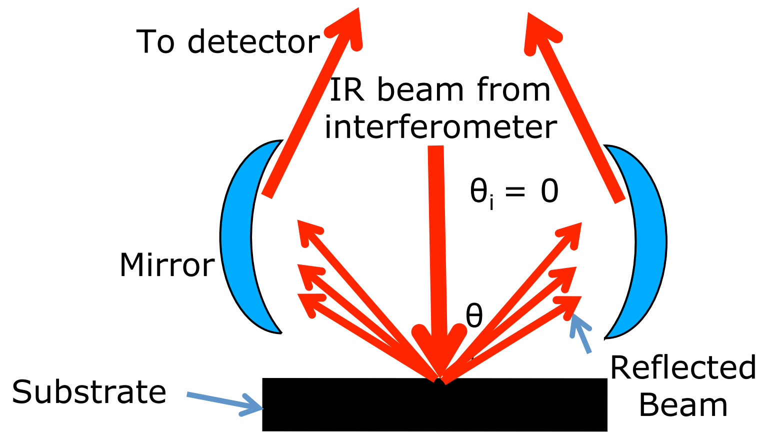
- Toray T800/3900 composites with various levels of thermal damage
  - SBS samples provided from Year 1 & 2 research
  - SBS samples thermally exposed in air
  - Locally damaged panels heated in air – UW/Boeing
- Sand SBS surfaces with 180 grit Al_2O_3 sanding pads
- Measure sanded surface with diffuse reflectance FTIR
  - 3 measurements per sample
  - 3 samples per time/temp

  9 measurements
- Use MVA to develop calibration curve for thermal damage
  - GRAMS IQ software

Materials and Process – FTIR

- Mid-IR data region: 4000 cm^{-1} to 650 cm^{-1}
- Diffuse reflectance sampling interface
- Data collection: 90 coadded scans with 16 cm^{-1} resolution for background and specimen

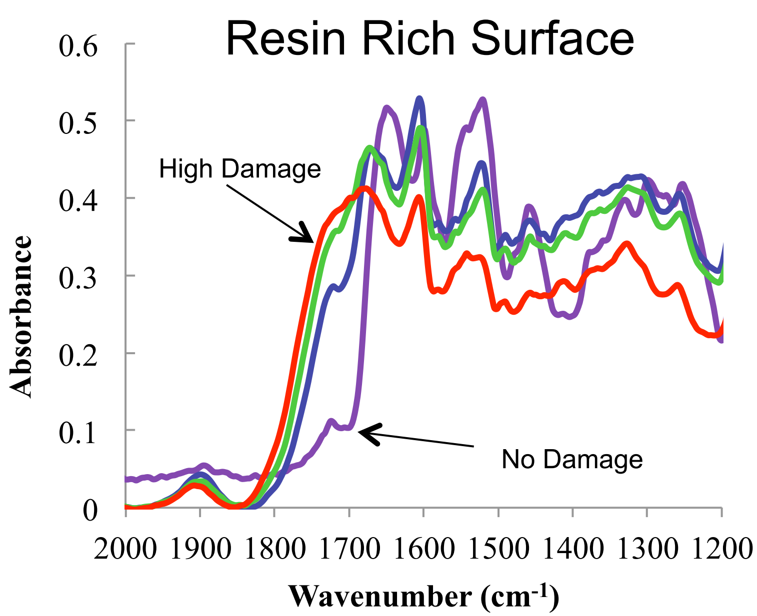
ExoScan FTIR

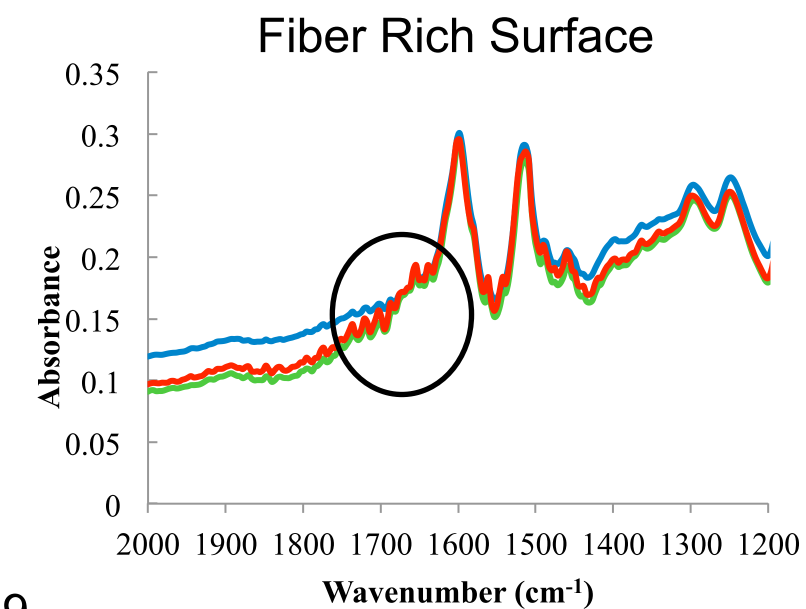


An infrared beam path for diffuse reflectance

Resin Rich vs. Fiber Rich Surfaces

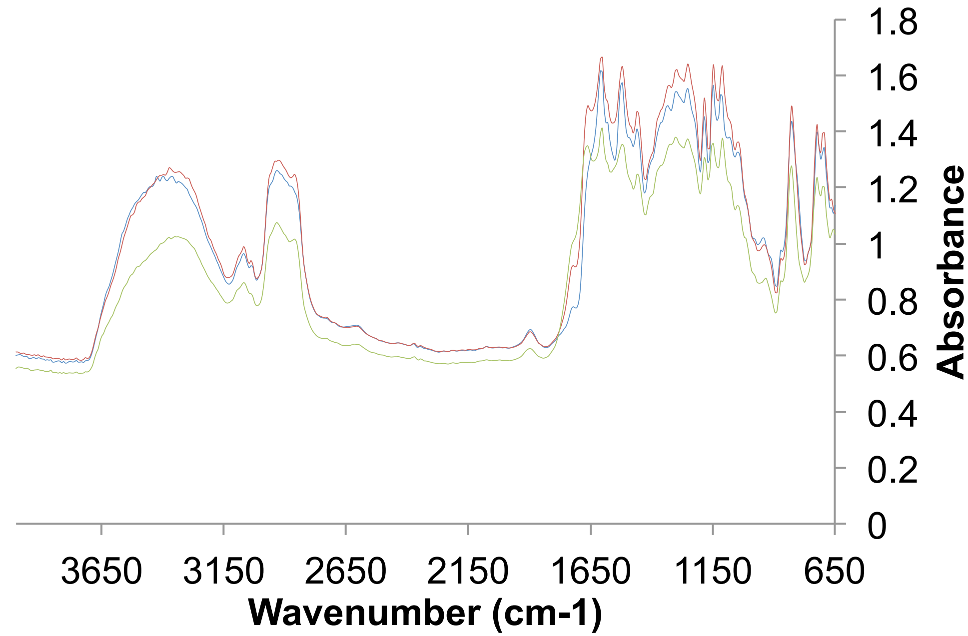
- Resin rich surfaces: oxidation peaks increase with damage
- Fiber rich surfaces: oxidation removed by sanding
  - Need MVA to determine differences in spectra and correlate to SBS data



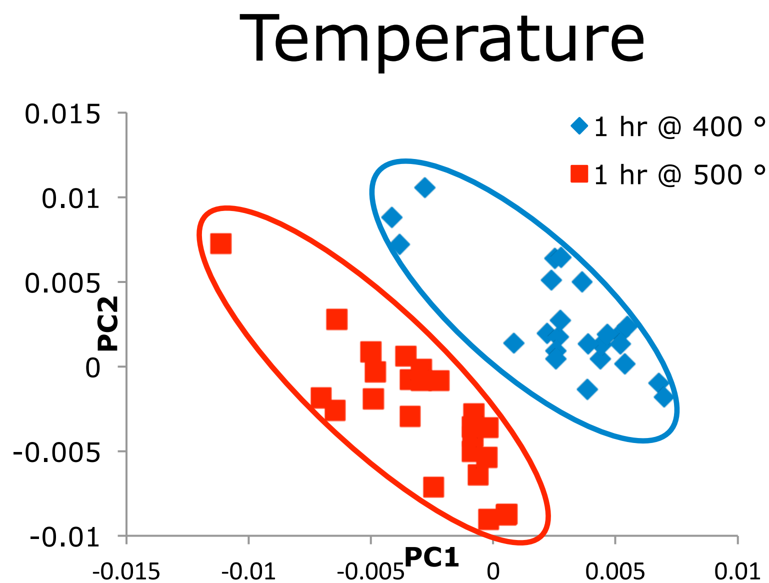


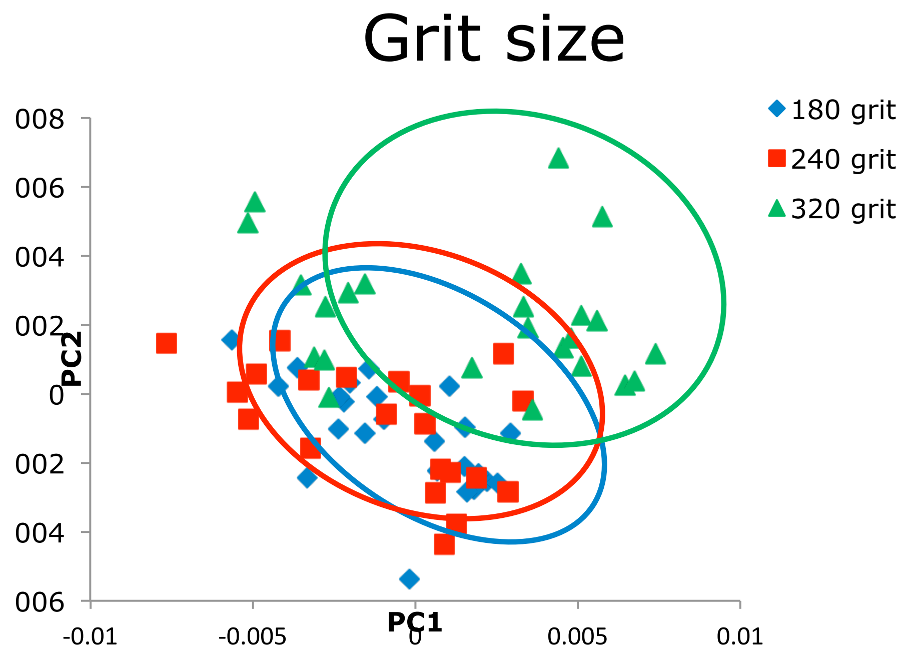
Spectral Analysis

- FTIR spectra of CFRP surfaces complex
  - Multiple constituents → many spectral peaks
- How to analyze spectra with confidence?
  - Multivariate analysis!
- Principal Component Analysis (PCA)
  - Exploratory to identify trends
  - Peak locations and intensities
  - Used to develop models



Effect of Sanding Variables on FTIR

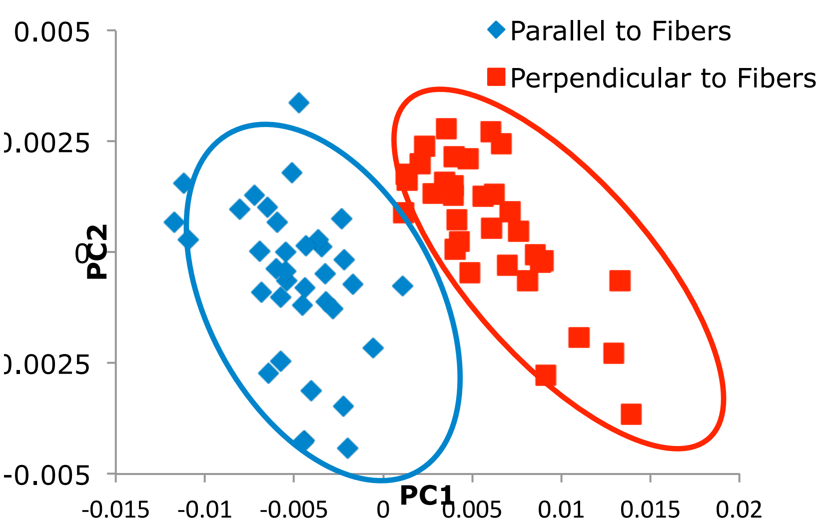




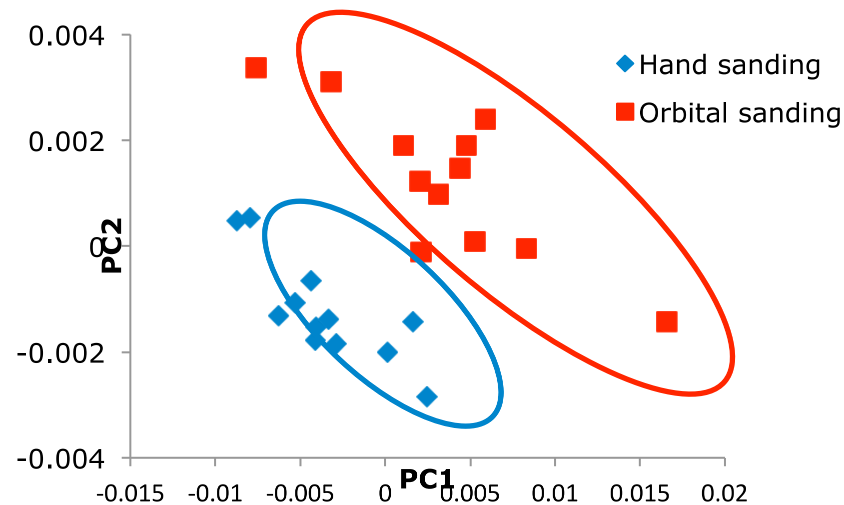
- Variables: temperature, method (hand vs. orbital), direction of sanding, grit size

Effect of Sanding Variables on FTIR

Direction of Sanding



Sanding Method

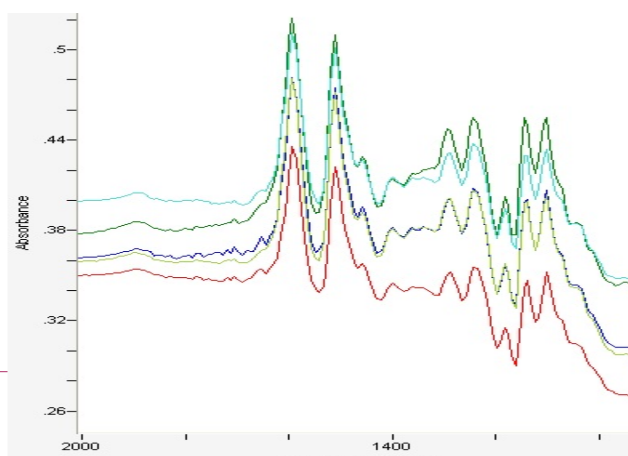


- FTIR Results influenced by sanding technique
- Measure consistent surfaces and develop model

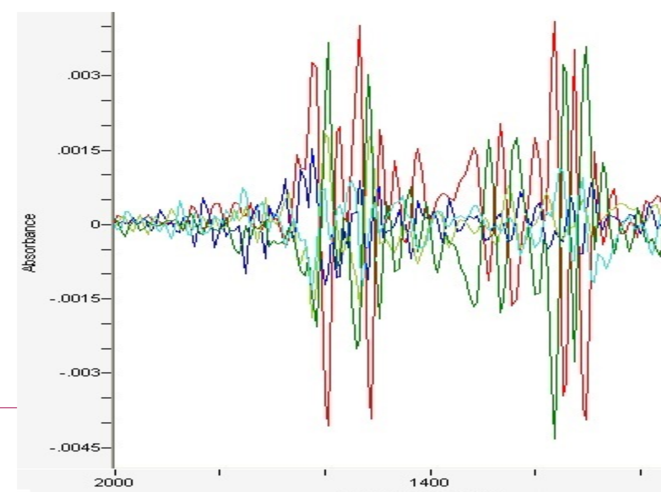
Developing FTIR Model

- SBS samples sanded and measured with FTIR
- FTIR spectra processed to remove baseline effects
  - 1st derivative with Savitzky-Golay 7pt smoothing
- Partial Least Squares model developed using MVA on processed spectra

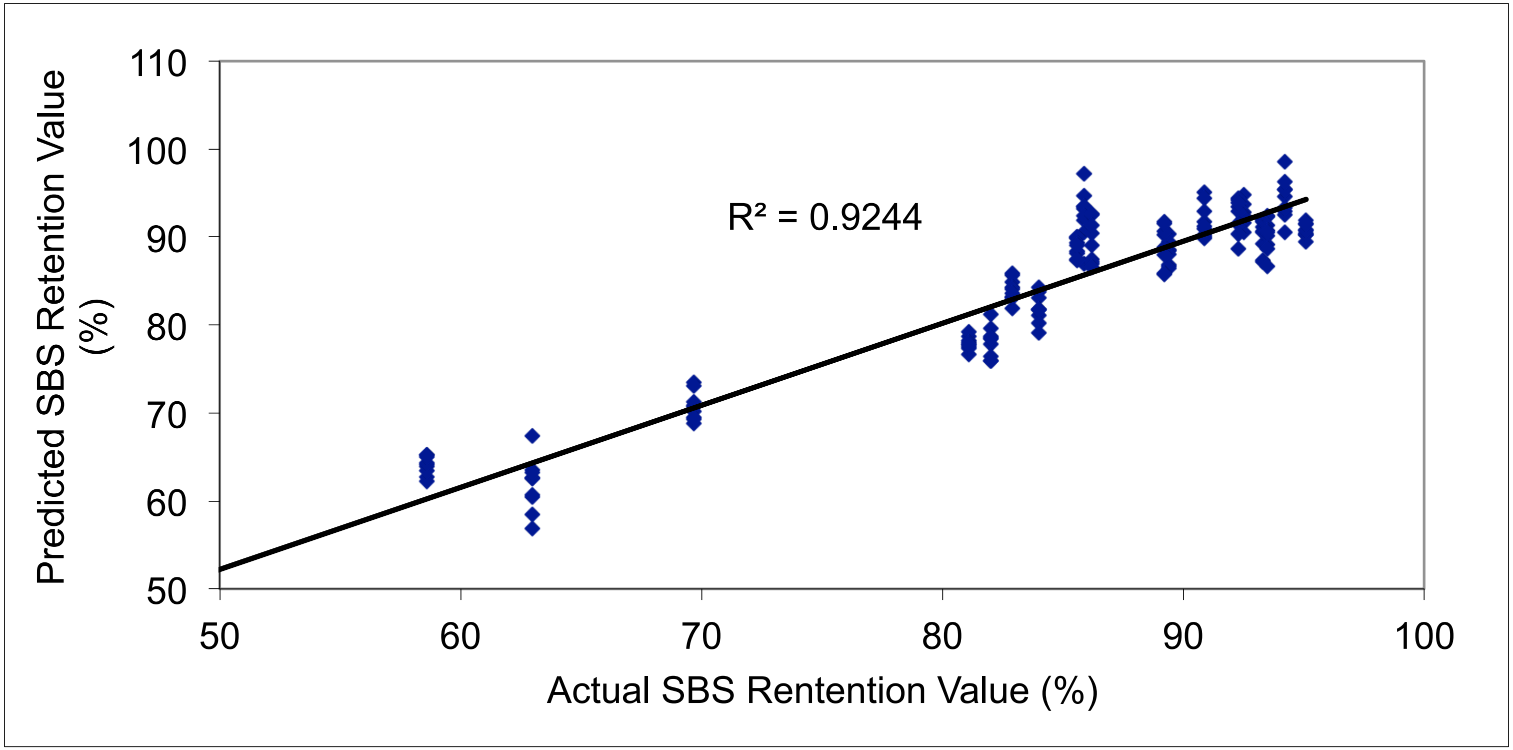
Raw Spectra



Processed Spectra

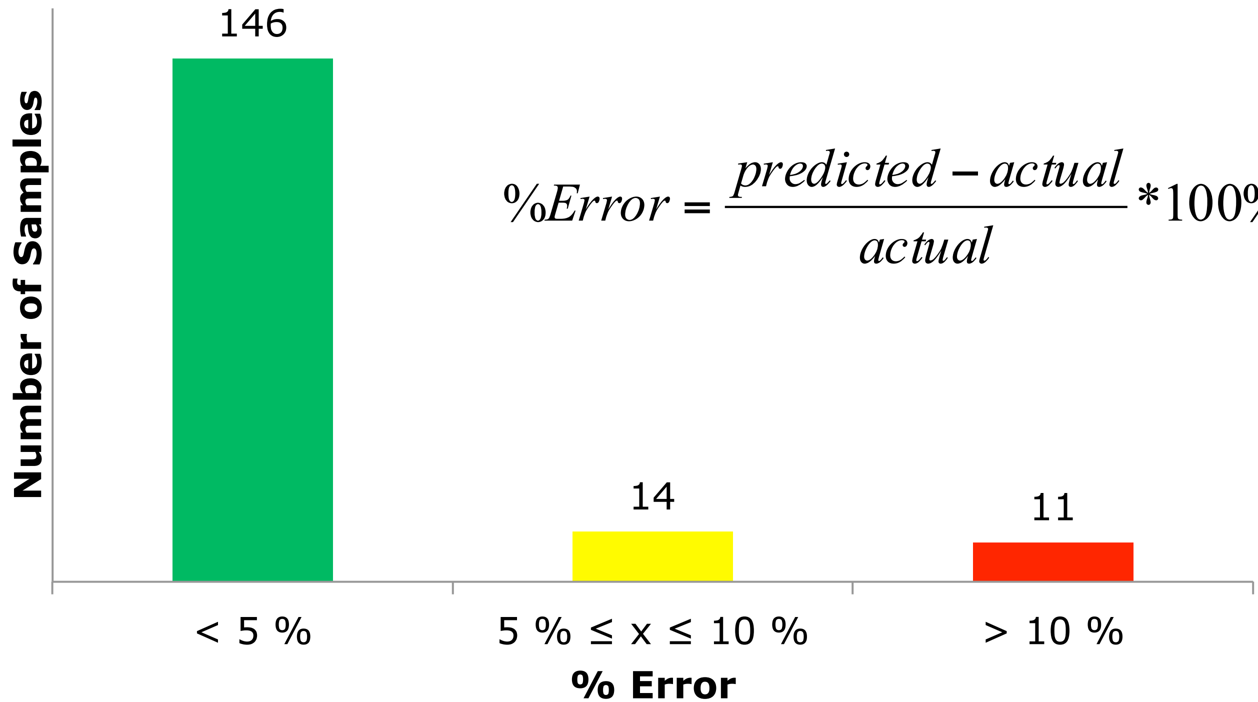


FTIR Model



✓ Data fits model

Model Validation



$$\%Error = \frac{predicted - actual}{actual} * 100\%$$

- Model used to predict SBS retention in independent evaluation set
- Error in model determined

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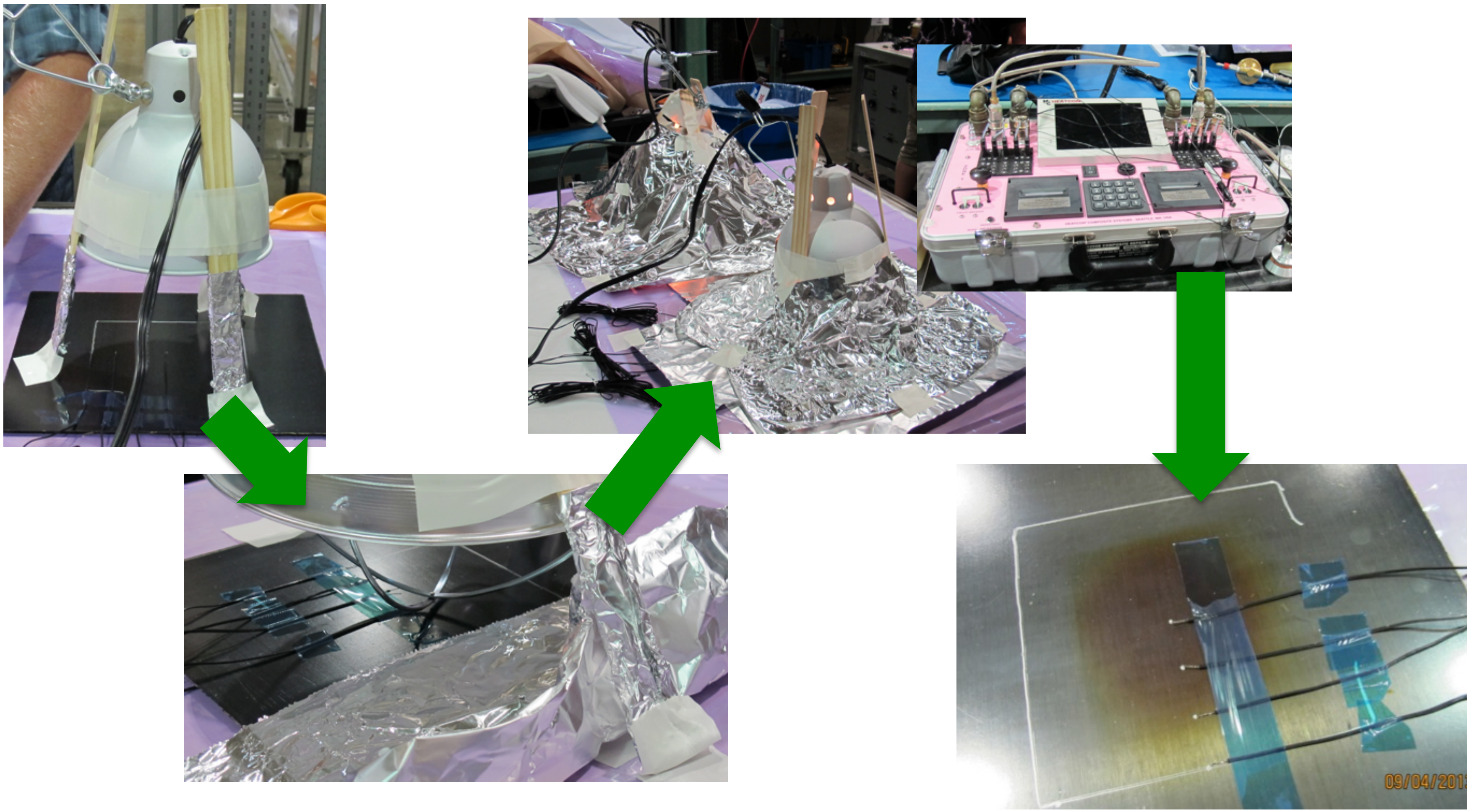
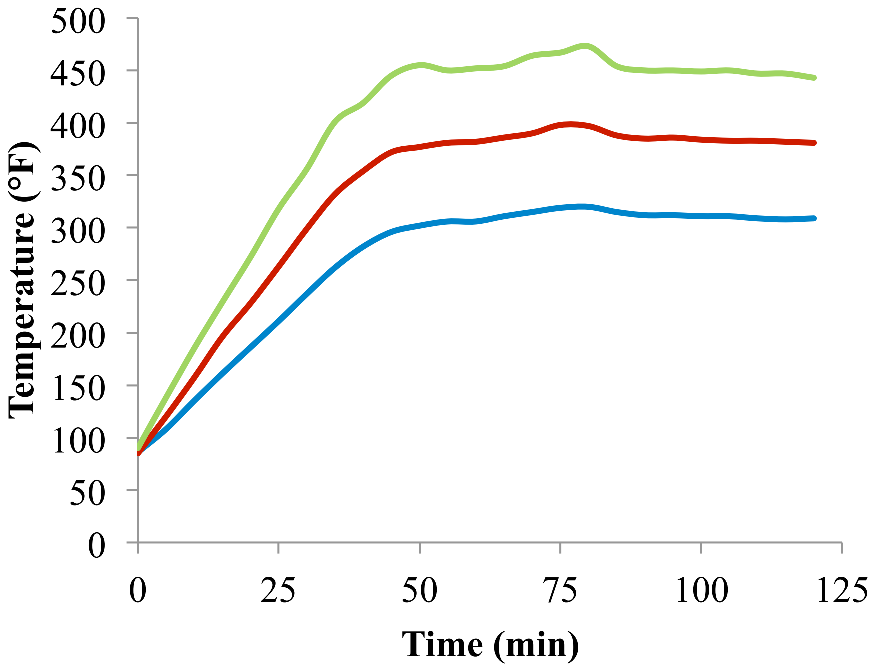
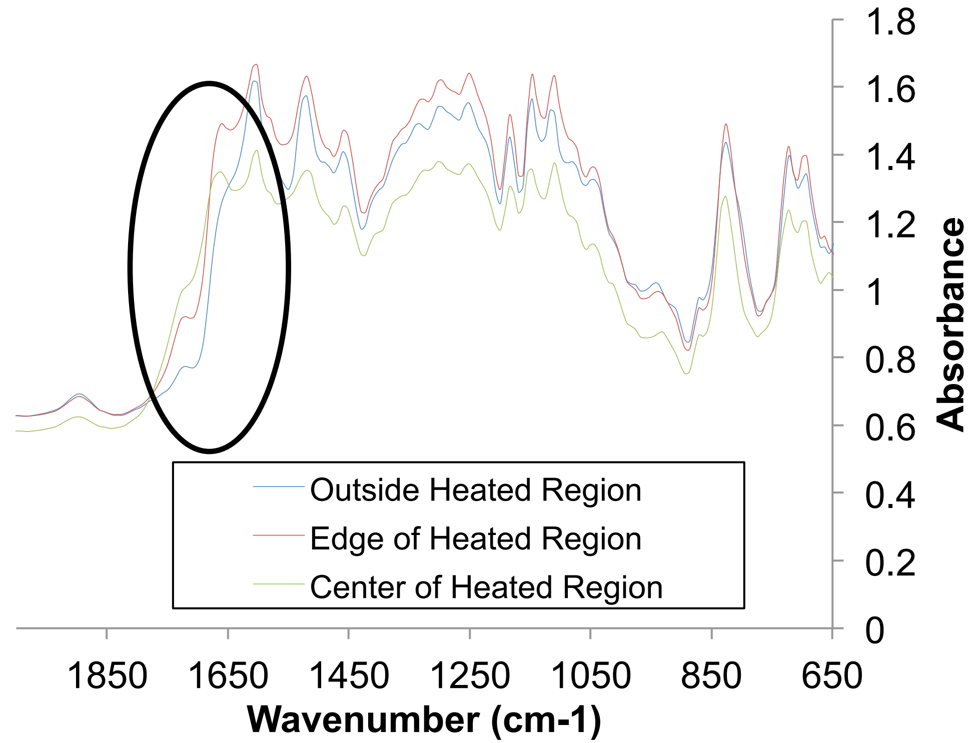
Localized Heat Damage – Process



Localized Heat-Damage Mapping





- Different levels of thermal damage detected by FTIR
  - Cut panels into SBS and dynamic mechanical analysis (DMA) samples for mechanical testing

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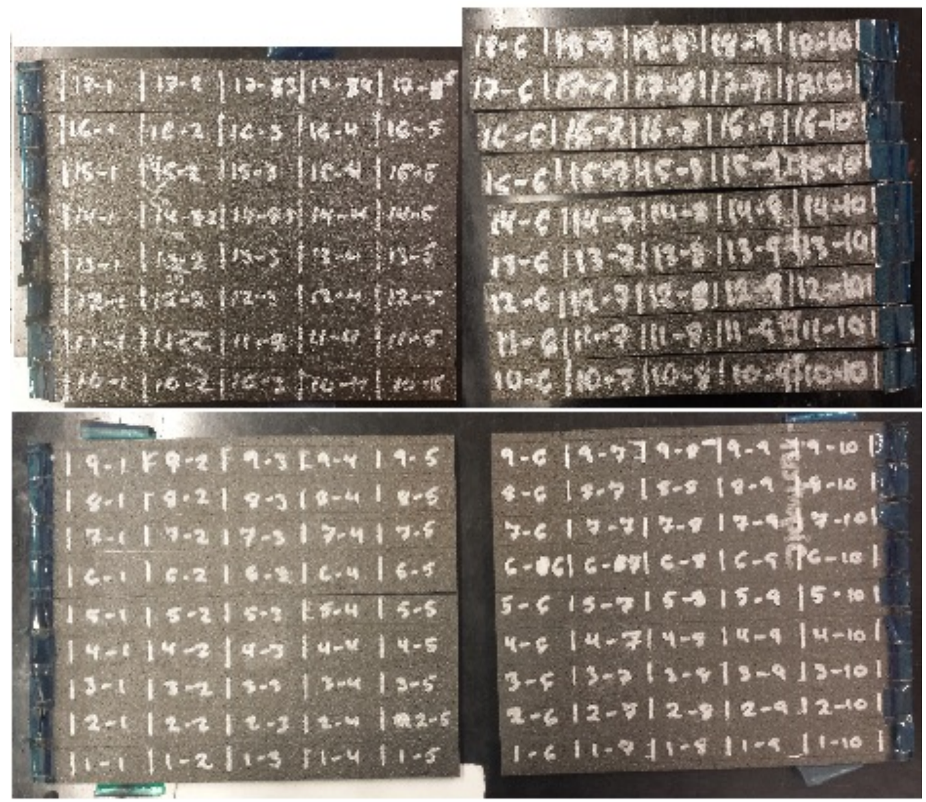
SBS and DMA Testing

- Damaged panel cut into SBS and DMA coupons
- Testing in progress
- Compare SBS and T_g to determine best method to correlate to FTIR



Summary

- FTIR measurements sensitive to surface finish
  - Need to test samples with consistently sanded surfaces
- Calibration model developed from SBS samples
  - Model predicted evaluation set well
- Panels created with localized thermal damage and surface mapped with FTIR
- SBS and DMA testing in progress to correlate mechanical damage to FTIR spectra

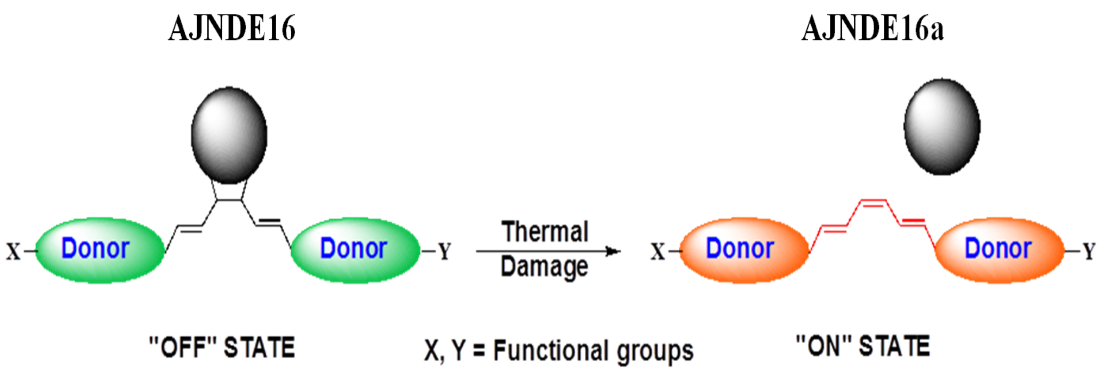
Future Work

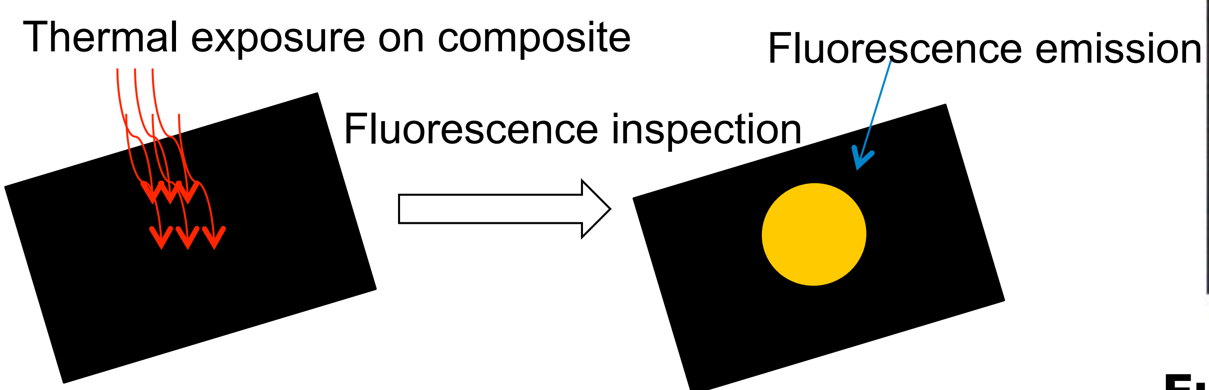
- Map thermally damage panels provided from Years 1 & 2 with FTIR
- Determine mechanical test to correlate damage to spectra
- Characterize thermally damage of panels provided from Years 1 & 2
- Perform scarfed repair guided by FTIR
- Test scarfed repair

Looking Forward

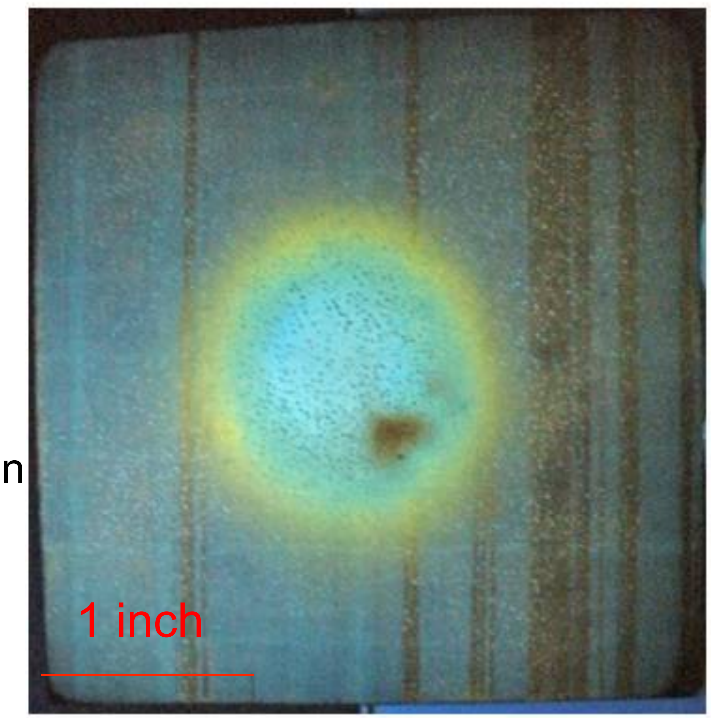
- Benefit to Aviation
  - Improved damage detection
  - Greater confidence in repairs
- Future needs
  - Application to other composite systems
  - Other applications of handheld FTIR
    - Chemical damage
    - Surface prep for bonding

Fluorescent Thermal Damage Probe





Probe-doped coating
1 hr @ 450 °F



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