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
  ▪ 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)

![Graph showing Short Beam Shear Strength Retention vs. Temp./Time for Epoxy 1](image_url)

- Onset of crack development visible in micrographs,
- No cracks visible in micrographs,
- Damage becomes visible in C-Scans.

CECAM  |  JAMS  |  AMTAS
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 Al₂O₃ 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
• Sample absorbs excitation light and emits light at longer wavelength than the absorbed light (fluorescence).
• Measure changes in intensity and wavelength at max intensity ($\lambda_{\text{MAX}}$) 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
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
Year 3 Results: Fluorescence of SBS Samples

- $\lambda_{\text{MAX}}$ red-shifts and intensity decreases with increasing exposure
  - $\lambda_{\text{MAX}}$ 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

![Graph showing FTIR measurements for Year 1 & 2 and Year 3 with high and no damage categories.](image-url)
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

Top down schematic of scarfed surface showing how fiber orientation changes at each layer
Year 1 & 2 Results: Localized Damage

- Hot spots created
- 3 temperatures
  - 440, 465, 490 °F
- 2 panels each
Year 1 & 2 Results: Map of Localized Damage

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