FTIR for Thermal Damage Inspection on Composite Aircraft

30 August 2022

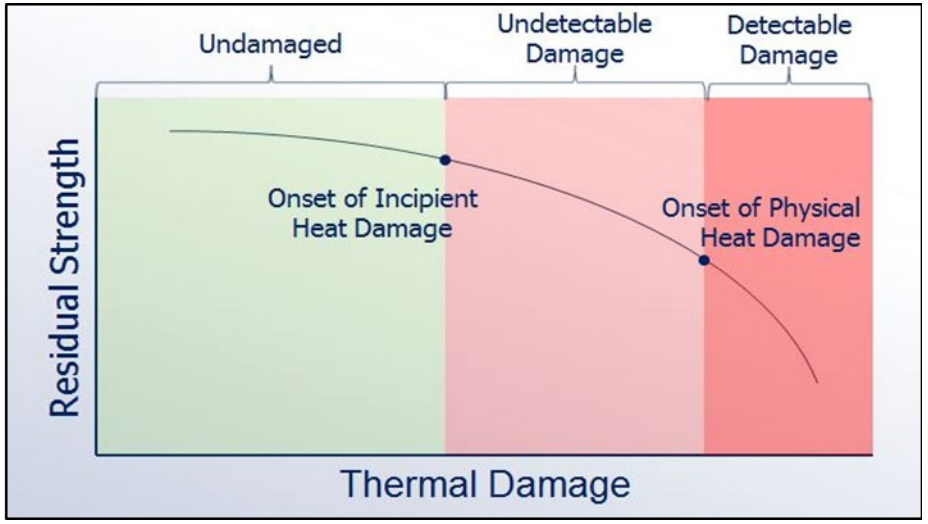
Presented to: Joint Technology Exchange Group (JTEG)

Presented by: Justin Massey

Use and Disclosure

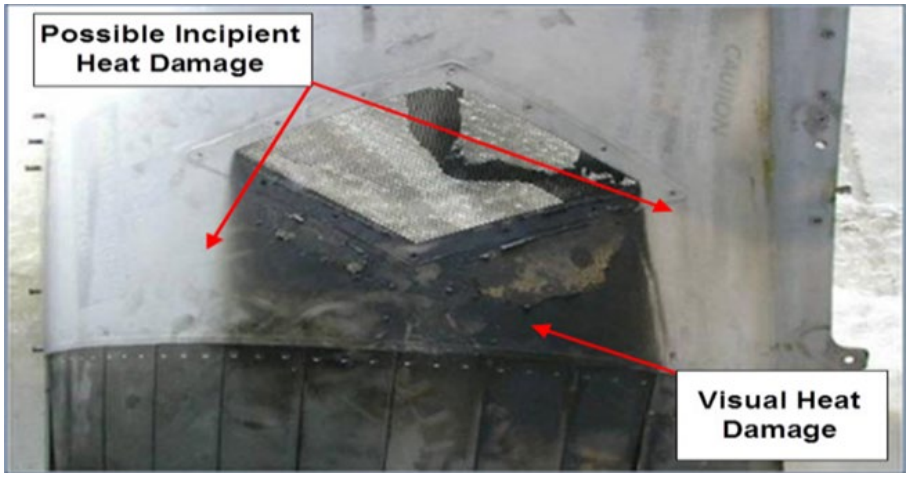
DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited, as submitted under NAVAIR Public Release Authorization 16-0003.

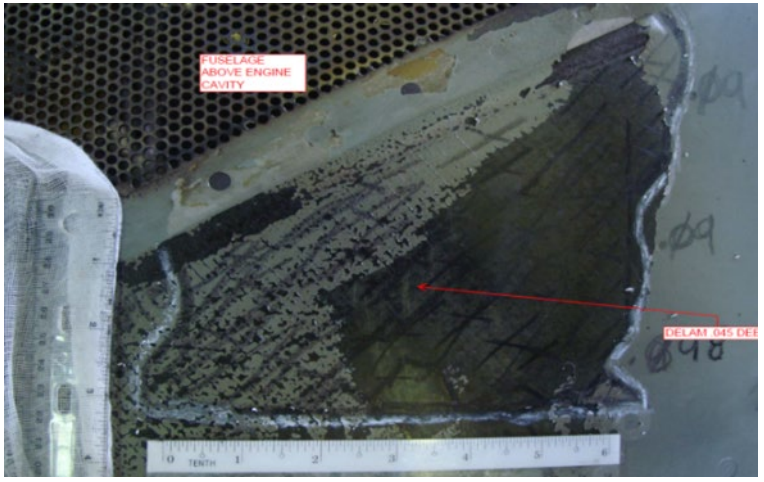
Problem



- Since 1970, the USN has been flying aircraft fabricated with advanced polymer matrix composite (PMC) materials. During aircraft operation thermal events occur and damage the PMC components.
- Two types of damage to the PMC material occur:
  - Incipient Damage (undetectable) – Change in polymer chemistry due to thermal exposure resulting in mechanical property loss.
  - Physical Damage (detectable) – Visual and NDT used for inspection.
- Could not quantify undetectable thermal damage and has resulted in estimated millions of dollars of scrapped aircraft components.

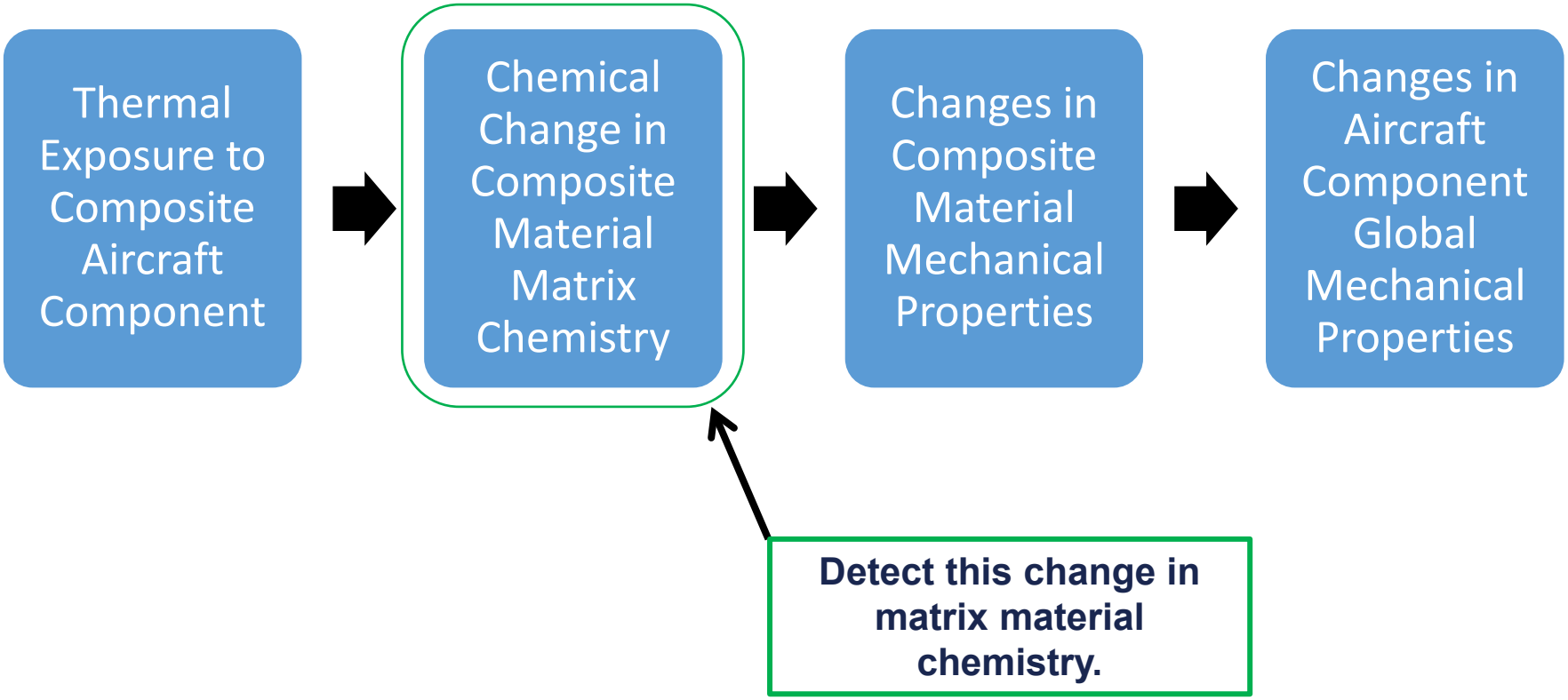
Previous Thermal Damage Inspection Process



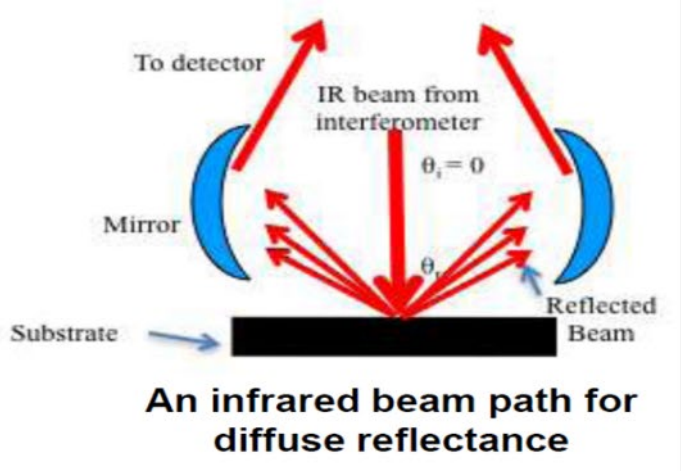


- Previously the heat damage evaluation criteria does not inspect for incipient heat damage. This results in very conservative repairs or most often a scrapped part.
- The current heat damage evaluation criteria is:
  - Visual inspection of top coat.
  - Visual inspection of primer.
  - Barcol hardness readings of composite material.
  - Ultrasonic inspection for physical damage (delams, etc.)
  - Visual inspection and hardness readings of surrounding metallic structure.

Incipient Heat Damage



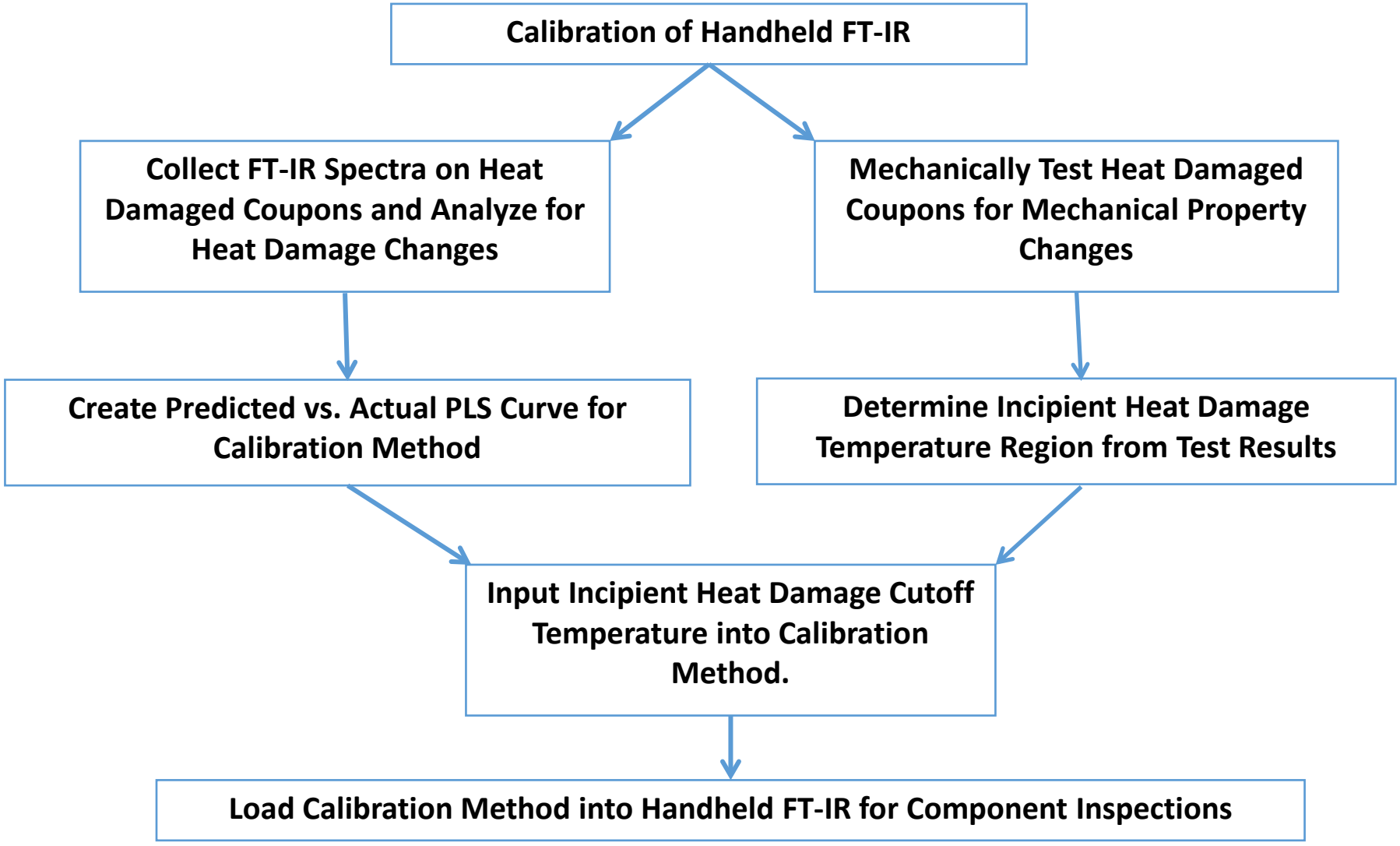
Solution: Handheld FT-IR



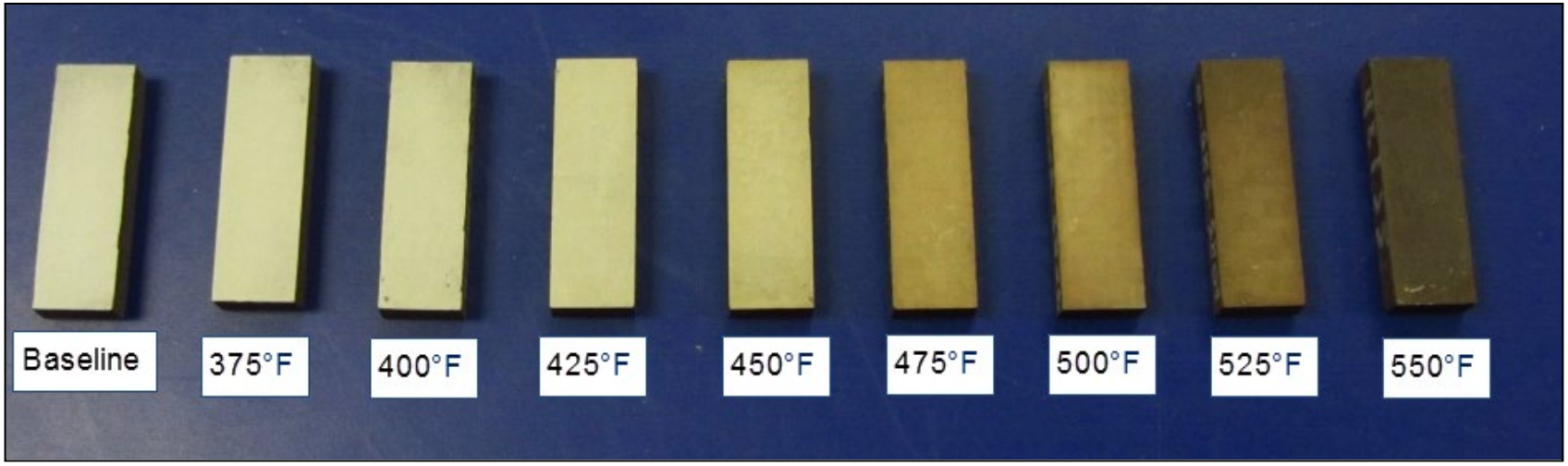
An infrared beam path for diffuse reflectance

- FITR: Fourier Transform Infrared Spectrometry
  - Mid-IR Spectral Surface Analysis
  - Excites molecules with Infrared Light with vibrations measured to determine surface composition.
- Agilent Technologies Flexscan 4200 FTIR
  - Portable diffuse reflectance FTIR unit.
  - Will be used to determine surface chemical composition changes due to heat damage.
  - Surface chemical composition changes will be correlated with mechanical test results for Flexscan calibration.
  - Boeing Commercial has developed this technology for 787 Dreamliner.

FT-IR Calibration

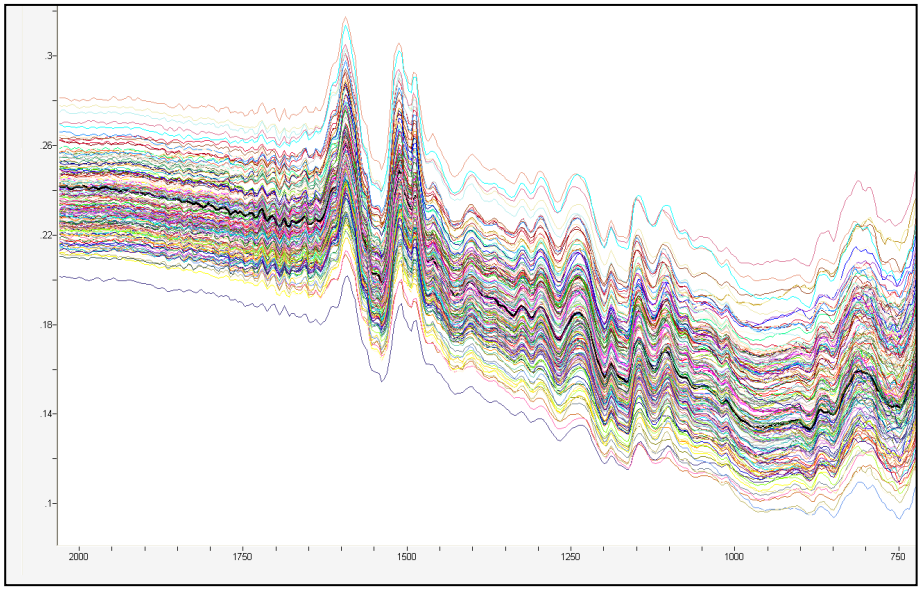


Coupon Preparation

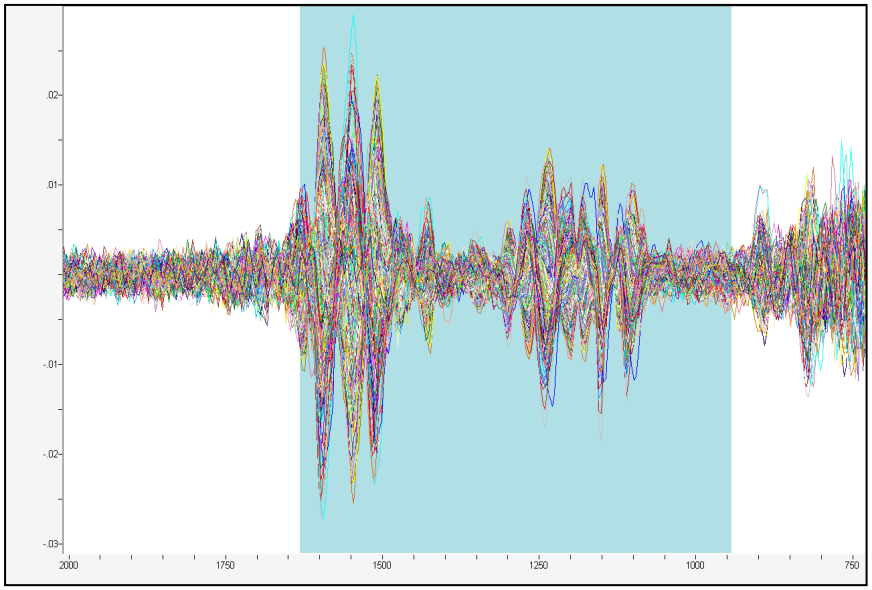


- Calibrations were made for carbon fiber/epoxy composite materials systems.
- Short Beam Shear (SBS) test coupons were fabricated to use for spectra collection and mechanical test data.
- SBS coupons were thermally exposed between 375-550°F in 25°F increments with a double sided NIST traceable process.
- All coupons were sanded to remove paint and primer prior to sampling.

Calibration Development



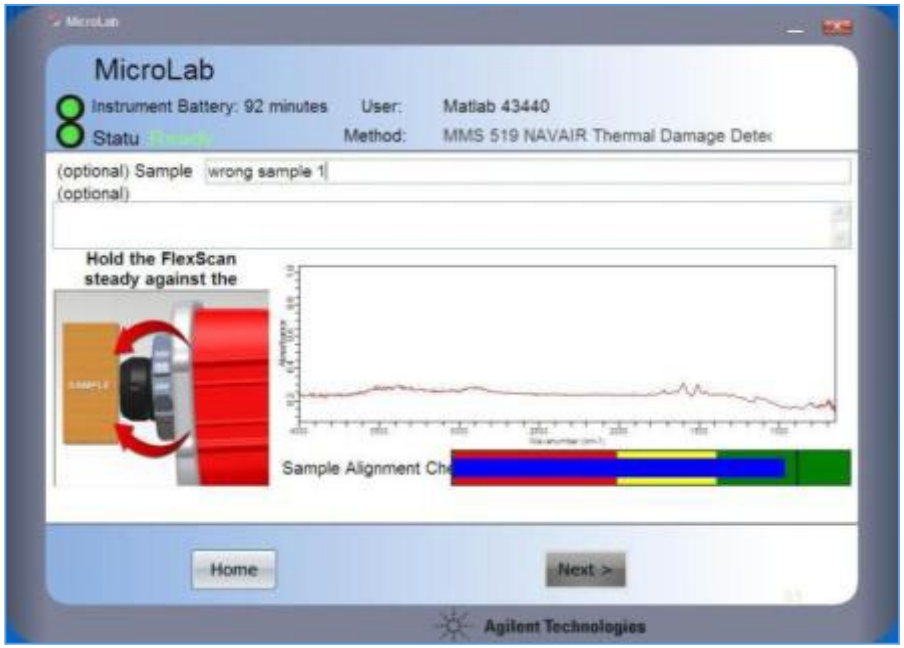
Raw Data

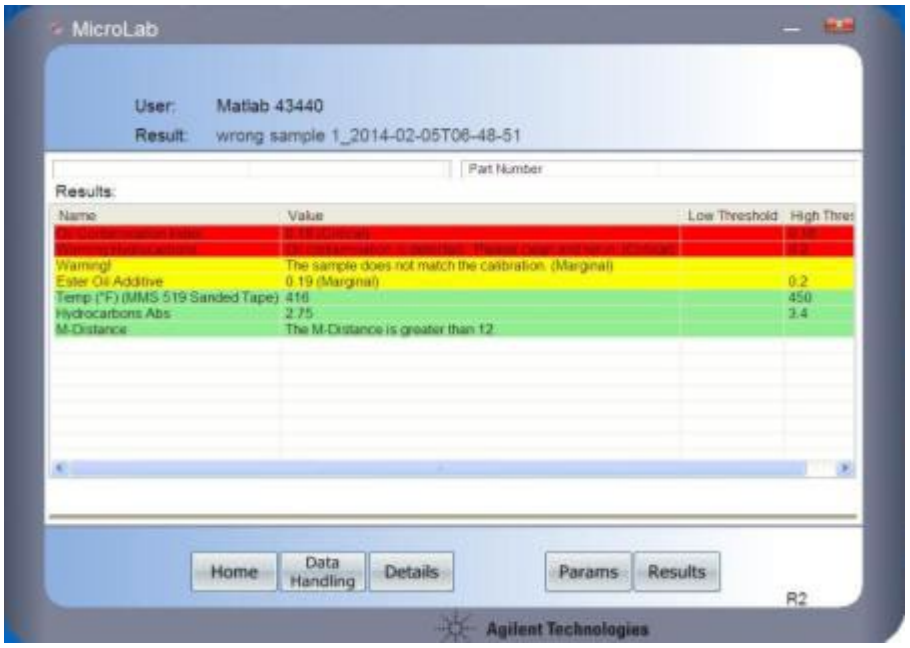


Processed Data

- Each material calibration method was created using 200 separate spectra.
- Frequency range = 2000-750 cm^{-1}
- Preprocessing of spectra performed using: Mean centered, Savitzky-Golay derivative.
- Partial Least Squares regression method used for calibration and validation.
  - 200 more separate spectra used for validation.
- Predicted exposure temperature vs. actual exposure temperature plotted.
- Methods evaluated by correlation factor (R^2), percent error, and RMS error.
  - Less than 4% error for all materials.

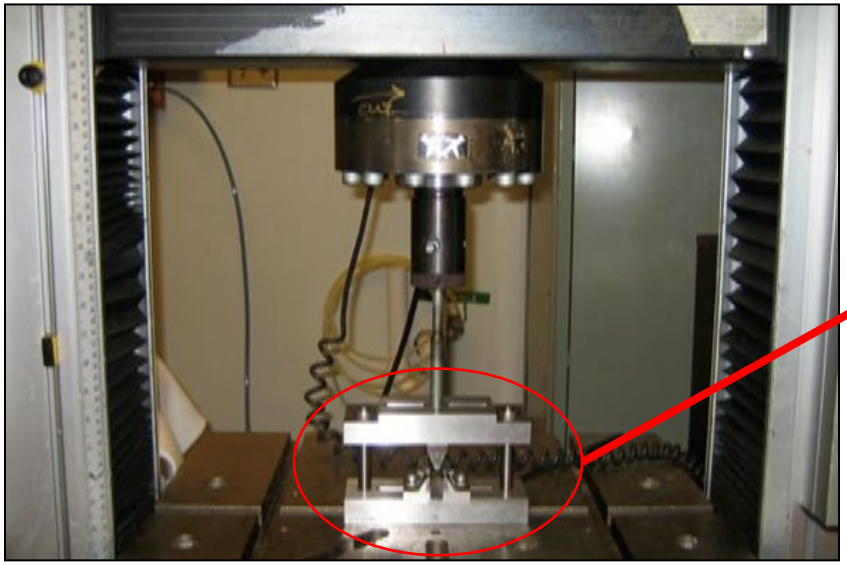
FT-IR Software

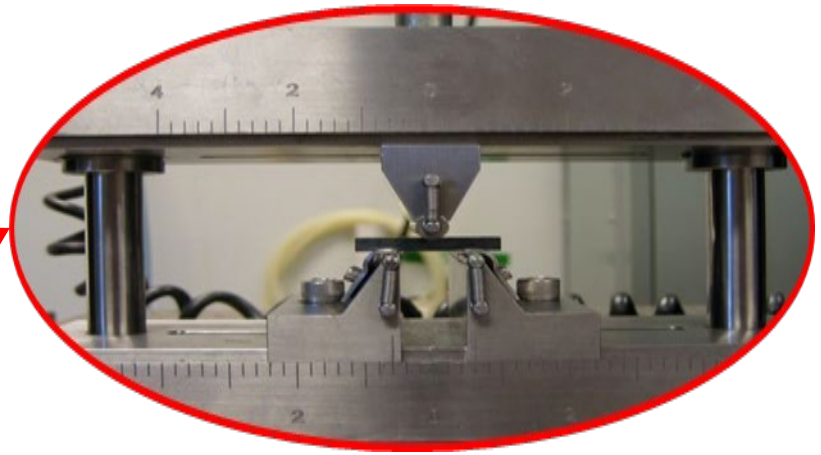




- An alignment bar was incorporated to ensure Flexscan is properly aligned with fiber direction during reading.
- Calibration includes a component to determine if the surface is contaminated.
- Mahalanobis distance was included to determine if the correct material calibration was used.
- Calibration will be uploaded with incipient heat damage temperature to determine good/bad cutoff.

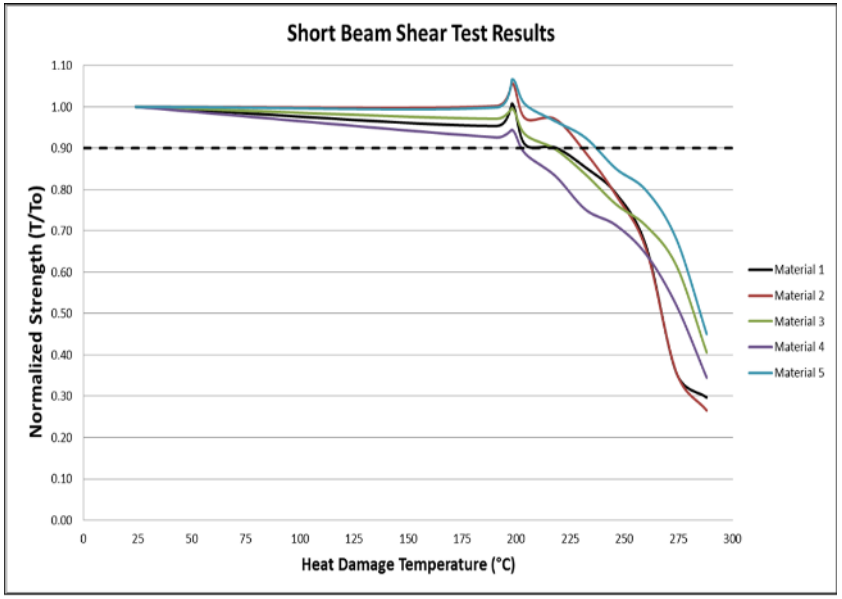
Mechanical Testing





- SBS was chosen because it is a resin dominated test.
  - Compared to other mechanical tests.
- All testing was completed at room temperature for all C/Ep composite materials.
- 5-10 coupons were tested for each sample set.
- A 1.5in x 0.5in x 0.25in thick coupon was used per ASTM D2344.
- Quasi-isotropic lay-up was used for each material system.

Material Properties



Material	Incipient Heat Damage Temperature	Physical Damage Temperature
Uni-1	397°F	525°F
Woven-2	439°F	525°F
Uni-3	416°F	550°F
Uni-4	393°F	550°F
Woven-5	450°F	525°F

- Onset of incipient heat damage temperature was determined from SBS data.
  - Incipient heat damage was determined when reduction in shear strength was approximately 10%.
  - 10% reduction was determined from plotting the lower bound of the standard deviation of SBS normalized strength vs. heat damage temperature.
- Onset of physical damage for each material was determined by ultrasonic pulse-echo A-scan of each coupon prior to testing.
- Validation completed with different time/temperatures.

Adoption as a Solution

- FT-IR has been adopted by USN since 2015 to inspect Carbon/Epoxy composite for incipient thermal damage.
- Used as a solution for 3 different aircraft programs.
  - Over $60M savings in aircraft and component repair.
- Currently being developed for 3 more aircraft programs.
- NAVAIR National WG developed to expand technology.
- Now used as a workhorse technology to provide inspection of thermal damage on composites

Application Example: Engine Fire on a V-22

- Fire event caused obvious visual damage to the RH nacelle and all its components which were scrapped.
- Due to proximity to the fire, the wing skin needed to be evaluated for incipient heat damage.
- FT-IR was used to evaluate the wing skin in about 5 hours and found no damage.
- Without availability of FT-IR the wing would have been scrapped for an estimated cost of $10 million.

Future Work

- Challenge: Current FT-IR is no longer supported by OEM.
- New FT-IR being developed as a drop in replacement.
  - Agilent 4300 Handheld FTIR
- Thermal Damage National WG developing an guidance document on how to create calibration methods.
- FRCSW developing thermal damage inspection courses for composites & metals.
  - Overview course: for Engineers and Managers.
  - Inspectors course: to train new thermal damage inspector for in-service aircraft.
- Develop a ruggedized version of the handheld 4300 FT-IR unit.

4200 FTIR

4300 FTIR

Conclusions

- Navy has created a Thermal Damage inspection methodology that incorporates new and legacy NDI techniques.
- FTIR calibration method were created for carbon/epoxy PMC material systems.
  - Less than 4% error on all calibrations.
- FTIR was adopted as the primary method for inspecting incipient thermal damage on aircraft carbon/epoxy PMC materials.
- Further development being completed to increase breadth of technology for different materials and aircraft programs.
  - Gen 3 FTIR being developed to replace old technology.