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Automated Fiber Placement Manufactured Composites for Science Applications

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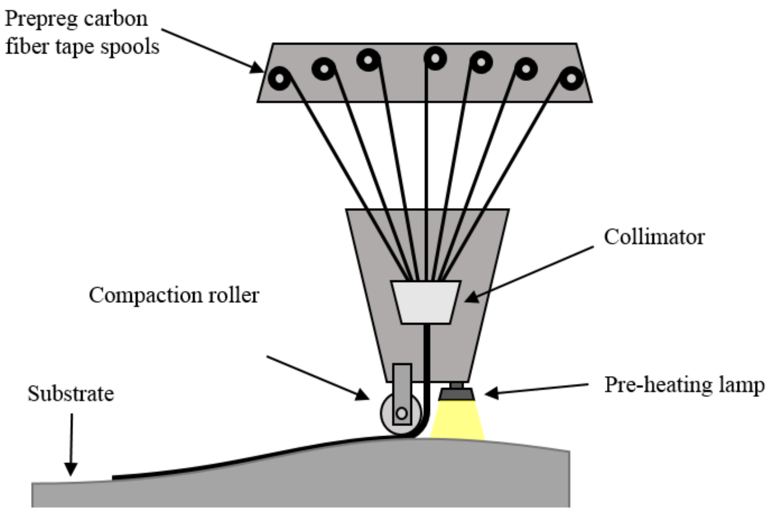
Today's Presentation

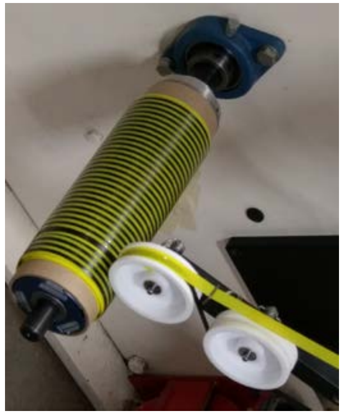
- Today you will learn:
  - What automated composite laminate manufacturing is
  - Why automation is of interest in science applications
  - How composite automation is being considered for science instrument applications
  - And, about test data showing high stiffness materials processed with automation results in reduced material strength while stiffness and coefficient of thermal expansion are mostly unaffected

Composite Automated Processing Center (Ref: Electroimpact)

Introduction – Automated Composite Processing

- Automated Fiber Placement (AFP) and Automated Tape Placement (ATP) are common in manufacturing large composite structures
  - ATP uses a material form ***greater*** than 75mm (3”) wide
  - AFP uses a material form ***less*** than 75mm (3”) wide
  - This work used 6 mm (1/4”) wide slit tape material





6 mm unidirectional slit tape from Toray Advanced Composites

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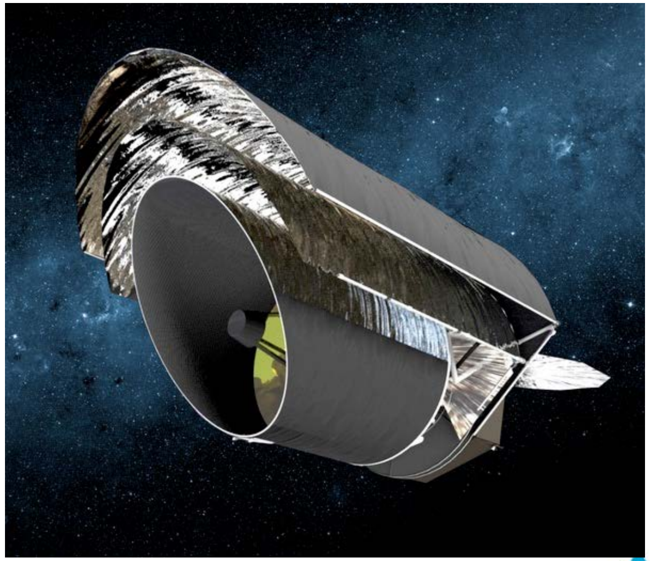
Introduction – The Need

Composite materials are extensively used in industry and government applications

- Larger aircraft and launch vehicle parts are commonly produced with automated manufacturing
  - Intermediate modulus fiber applications (Hexcel IM7) with toughened epoxies
- Spacecraft instrument structures are getting bigger
  - HST: 2.4 m diameter mirror
  - JWST: 6.5 m diameter mirror
  - The next flagship missions such as LUVOIR and Origins Space Telescope are bigger than JWST
  - Space Launch Vehicle (SLS) is exploring 8.4 and 10 m diameter fairing configurations. Instruments will be designed to fill that gap!

Boeing 787
Composite
Fuselage Section
Approximately 6m

2020 Decadal Survey : Next NASA Flagship Missions



Origins (concept shown) : 6 and 9 m diameter optic variants

LUVOIR: 8 and 15 m diameter optic variants

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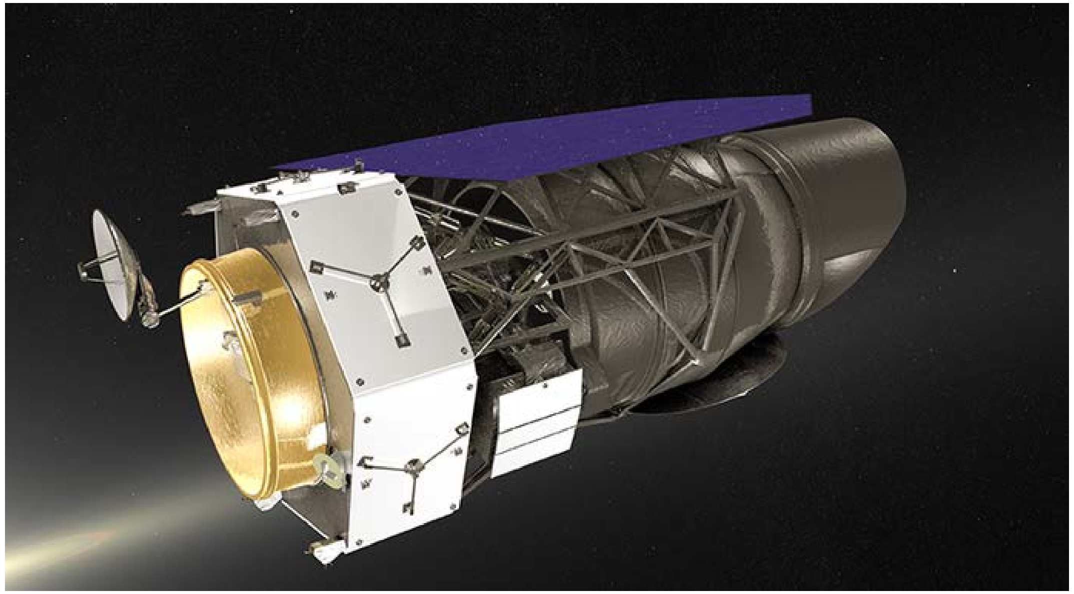
Introduction – The Question

- Space instrument structures have different requirements than launch vehicles and aircraft
  - High dimensional stability, high stiffness, and low outgassing
  - High modulus fibers (e.g Toray M55J) with cyanate ester resin systems are needed
- Increasing instrument size leads to using industrial capability to decrease science structure costs
- *This study seeks to answer the question: 'can high stiffness composites materials be processed on automated composite manufacturing centers and maintain needed properties ?*



WFIRST Concept
Outer Barrel Assembly is ~3.6 m diameter

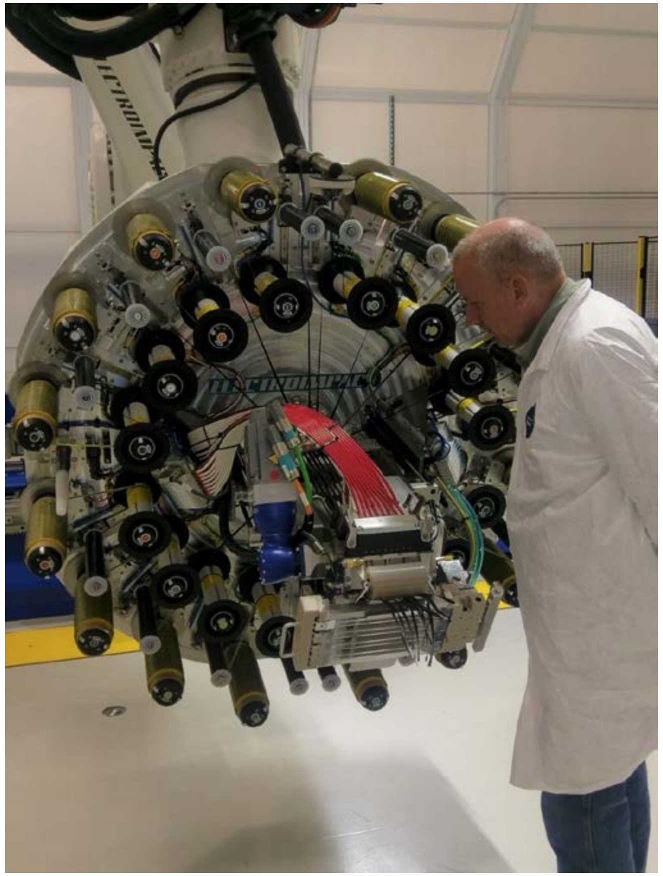
Material – What is the Concern?

Why is this a relevant question?

- Stiff fibers do not form as well as less stiff fibers
- Materials used for automation goes through more processing steps
- Automation steps apply forces not seen in hand-layup

These have the potential to damage fibers and thus effecting material performance

Tape slitting: extra steps to take 305mm (12”) wide material to 6mm (1/4”) wide



AFP Head Shown: Complex fiber path, Pneumatic forces, high process speeds

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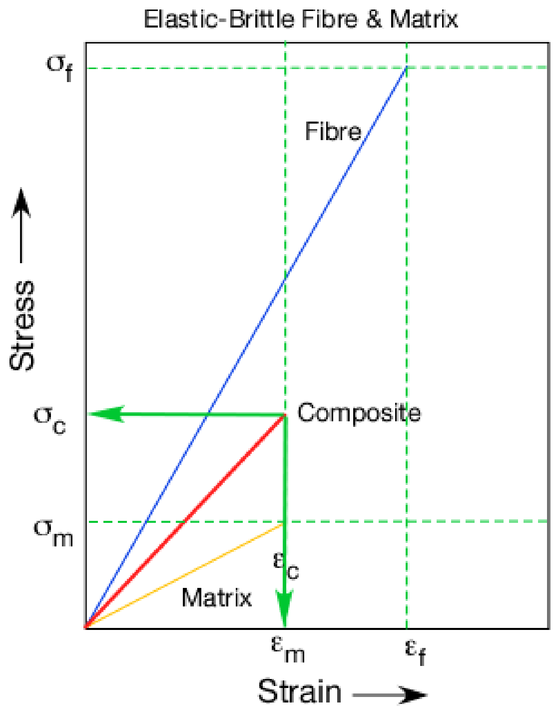
Approach

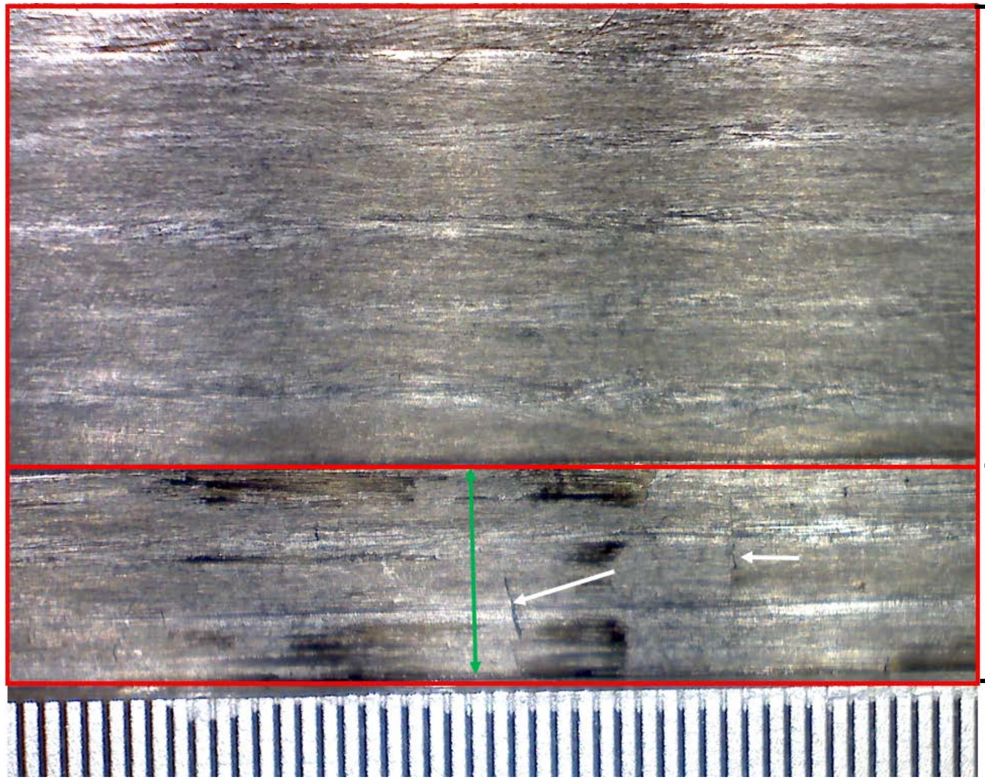
- Choose a baseline material common to science instruments
  - Tencate provided M55J/RS3C 6K 145GSM 36% RC material for this effort
- Compare performance of panels manufactured by traditional and automated lay up methods
- Evaluate performance based on standard tests
  - ASTM 3039: Standard Test Methods for Tensile Properties of Polymer Matrix Composite Materials
    - Tensile modulus and strength testing
  - ASTM E297 Standard Test Method for Linear Thermal Expansion of Rigid Solids with Interferometry
    - Coefficient of Thermal Expansion (CTE) testing
- *What follows - Test design, work performed and the results*



$$\Delta L/L = \alpha \Delta T$$

Prepreg Material - 1st Batch

Manufacturer and the relevant processing temperatures				
Slit Tape Processing Temperature	1st Batch	22 ⁰C	2nd Batch	27 ⁰C



- 1st material batch incoming inspection showed the 'appearance' of cracks

- Tencate slit a second batch of material using a slightly higher processing temperature, and used a less stiff backing material

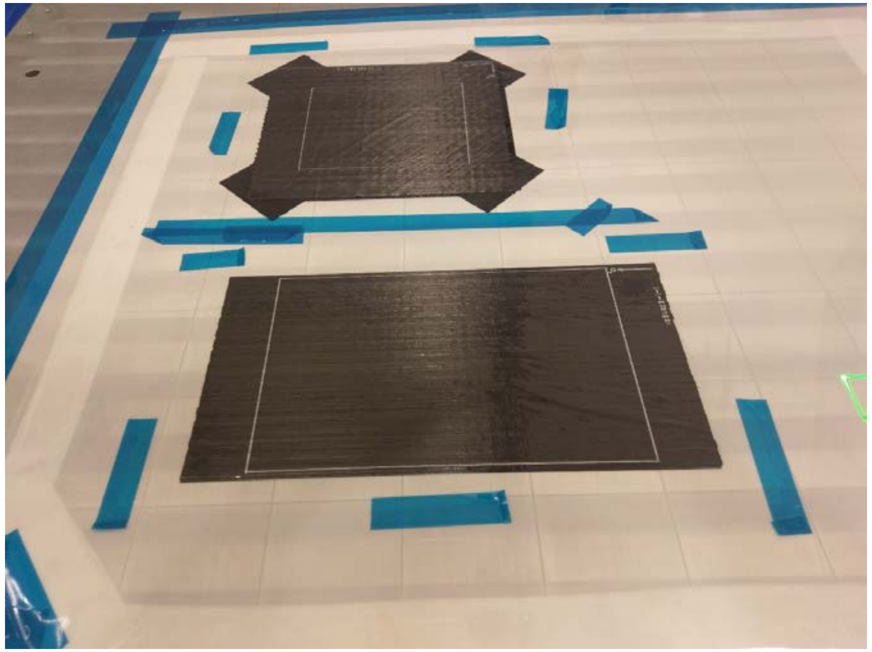
  - The feature observed in the first batch was not observed on the second batch of material

Laminate Manufacturing

Panel Design and Test Variants Investigated

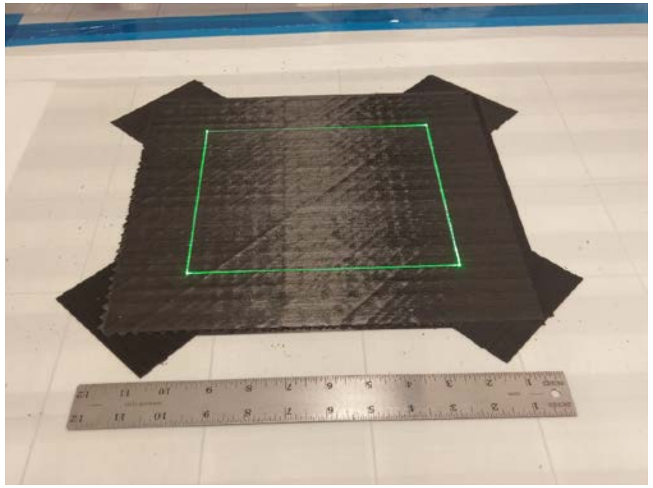
- [0,45,90,-45]s Quasi-Isotropic panel for CTE testing
- [0]6 panels for tensile modulus and strength testing

Lamination and Manufacturer Processing Parameters				
	LaRC		MSFC	
	Hand Layup	AFP	Hand Layup	AFP
Slit Tape Processing Temperature	N/A	22 ^{0}C	N/A	27 ^{0}C
Lamination Processing Temperature	21 ^{0}C	21 ^{0}C	N/A	22 ^{0}C and 26 ^{0}C



Laminate Manufacturing

- All processing performed at NASA
  - Langley Research Center (LaRC)
    - Hand layup and AFP
  - Marshal Space Flight Center (MSFC)
    - AFP
- Identical Processing
  - Identical machine settings
  - Identical cures
- Ultrasonic NDE performed, no defects reported



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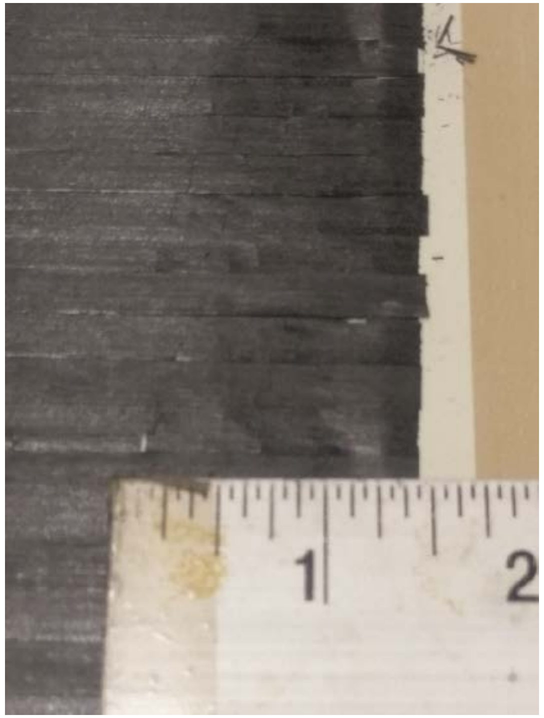
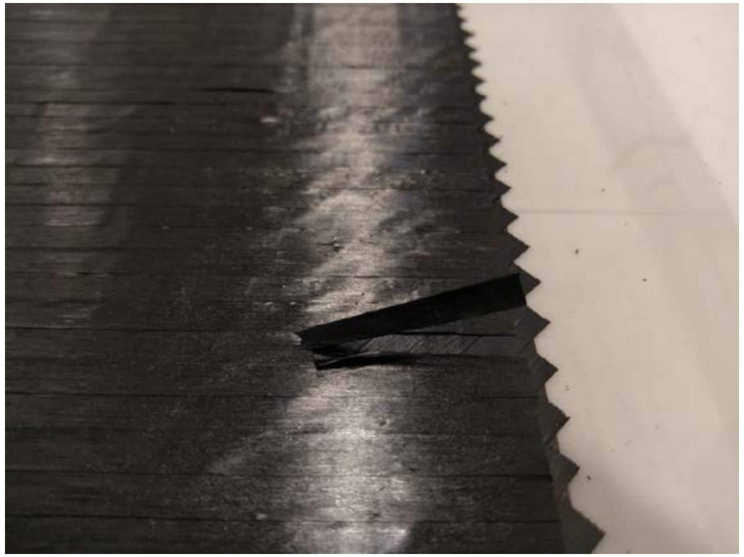
Laminate Manufacturing – In process Evaluations

- Observed tow fractures during AFP
  - Most occurred within 50 mm from the end of layups.
  - local to where the pneumatics that drive the clamps and the cutters are located
- Higher AFP processing temperatures mitigated this effect





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Tensile Test Results

- Tension testing was performed both at GSFC and LaRC
- 1st one failed in grips due to excessive grip pressure
  - data not used
- All others failed explosively as would be expected in a [0] ply coupon

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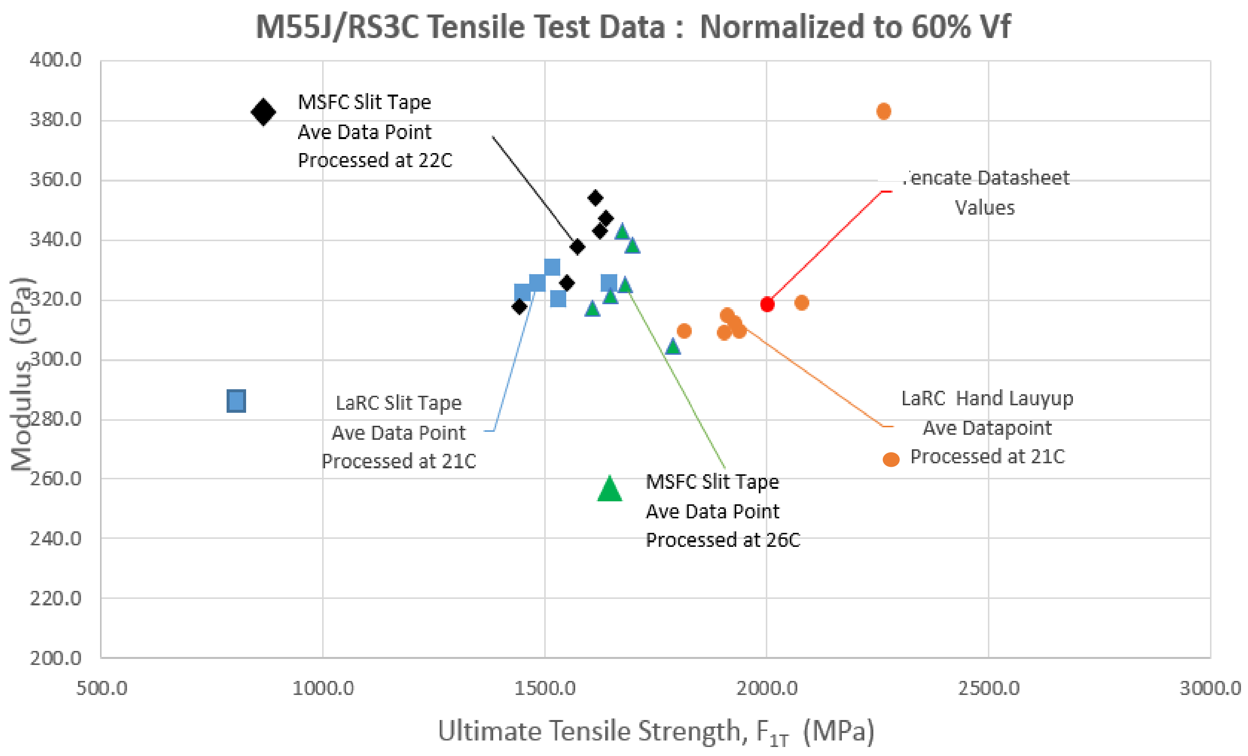
Tensile Test Results

Baseline is Tencate RS3 Datasheet

- Hand lay up tension modulus and strength meets baseline data within 3%
- All AFP Moduli are within 6% of baseline data
- AFP tensile strength does vary
  - AFP at RT / Slitting at RT
    - Strength 29.7% lower than baseline
  - AFP at RT / Slitting at Elevated Temp
    - Strength 23.9% lower than baseline
      - 5.8% recovery
  - AFP at Elevated Temp / Slitting at Elevated Temp
    - Strength 17.3% lower than baseline
      - 12.4% recovery
- AFP studies* on other materials show effects on properties are around 5%

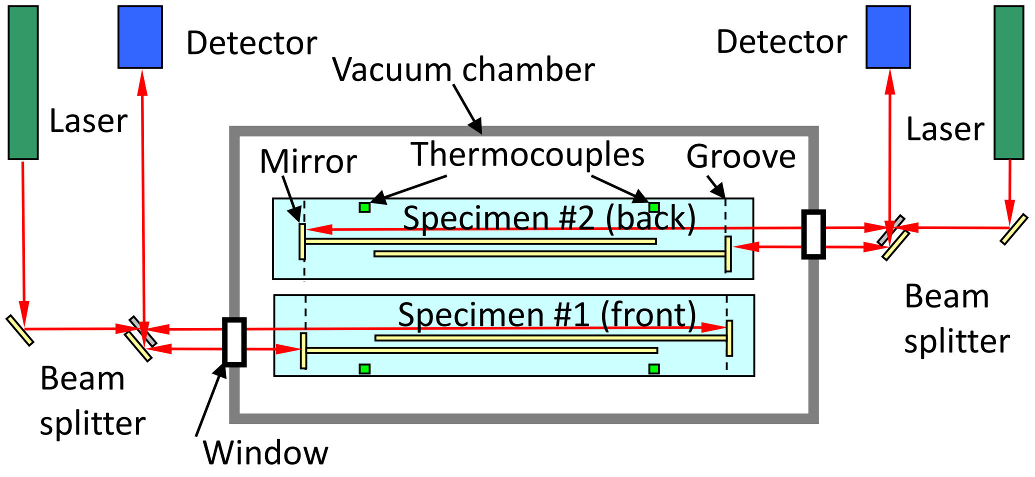


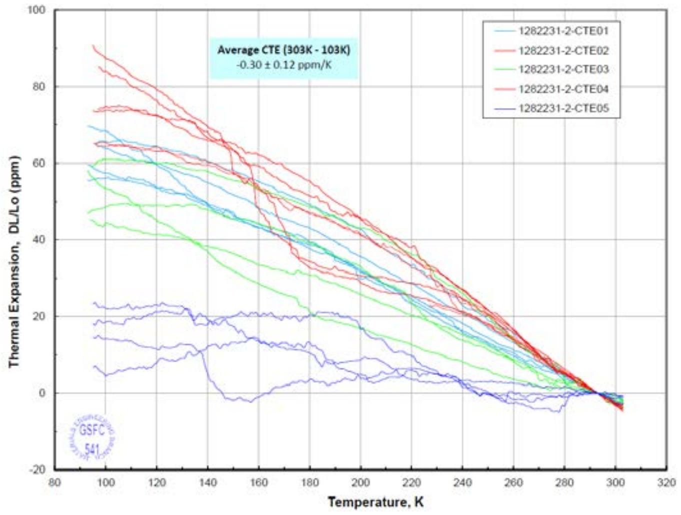
*Croft, K., et al, "Experimental Study of the effect of automated fiber placement induced defects on performance of composite laminates." Composites: Part A 42 (2011) 484-491)

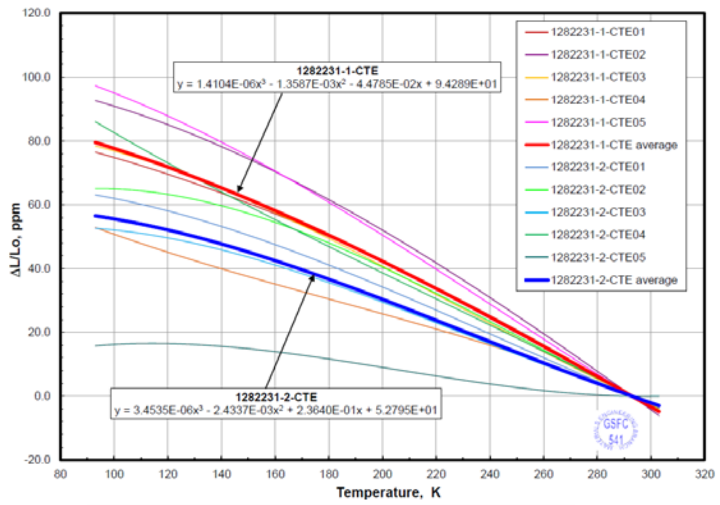
CTE Testing Described

CTE Setup and Measurements

- CTE measured with a Michelson interferometer (per ASTM E289-17)
- Minimum of 3 coupons from each panel type
- No coupon preconditioning
- Measured from 323 to 98 K (50 to -175 ^{0}C)
- Each measurement cycle repeated at least 3 times
- Best fit applied to averaged thermal expansion data to get a 3rd order polynomial
    - Derivative of the polynomial reported as CTE measurement







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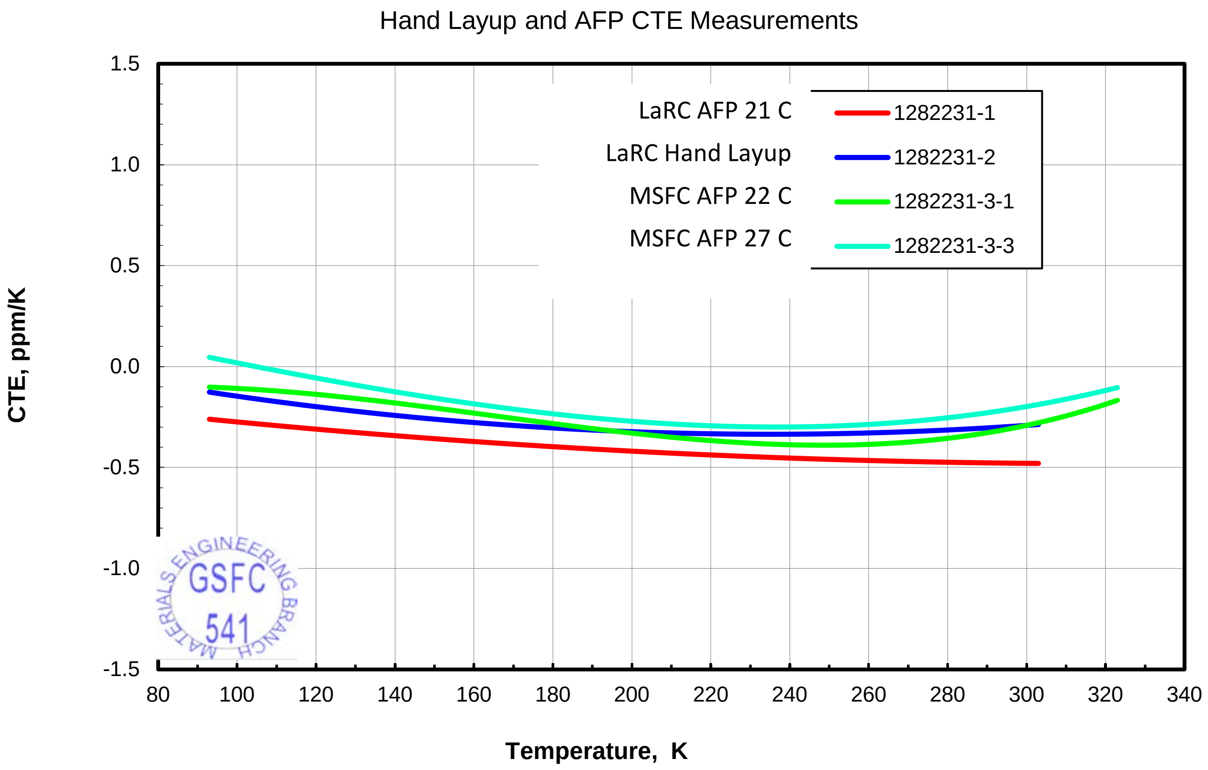
CTE Test Results

QI Laminate – Expect Near Zero CTE

Reporting average over temp range

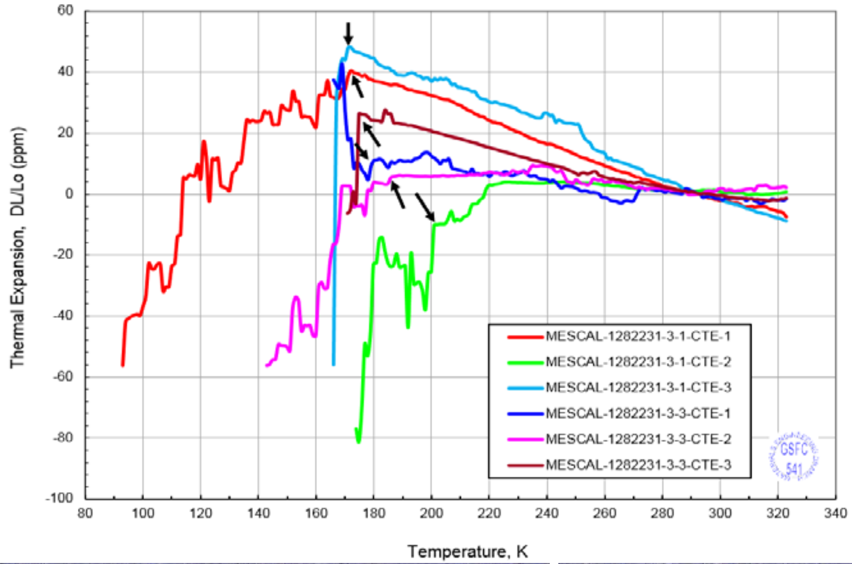
- Hand Layup CTE
  - -0.3 ppm/K
- LaRC AFP processed at 22 ^{0}C
  - CTE -0.4 ppm/K
- MSFC AFP processed at 22 ^{0}C
  - CTE -0.2 ppm/K
- LaRC AFP Processed at 27 ^{0}C
  - CTE -0.3 ppm/K
- Error +/- 0.1 ppm/K (based on standard deviations)

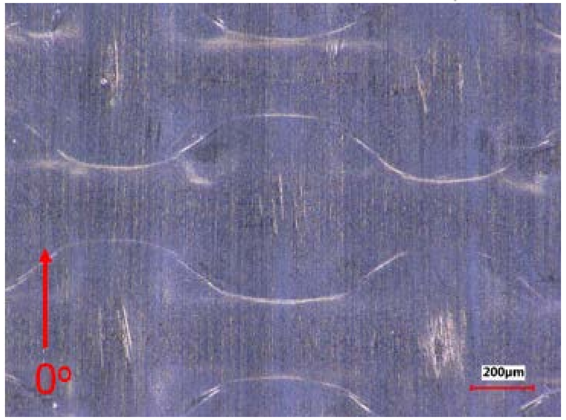


Tensile Test Results

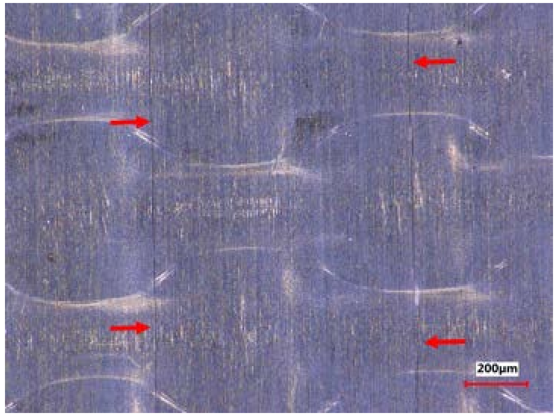
Interesting Finding on most MSFC Cycled CTE Coupons

- Upon 1st cool down all 6 coupons had a sudden change in thermal expansion
  - Occurs between 200 and 170 K
    - Thermal expansion data not valid after that because mirrors moved
- Surface inspections indicated cracking
  - This is seen parallel to the fiber direction





Before Thermal Cycle

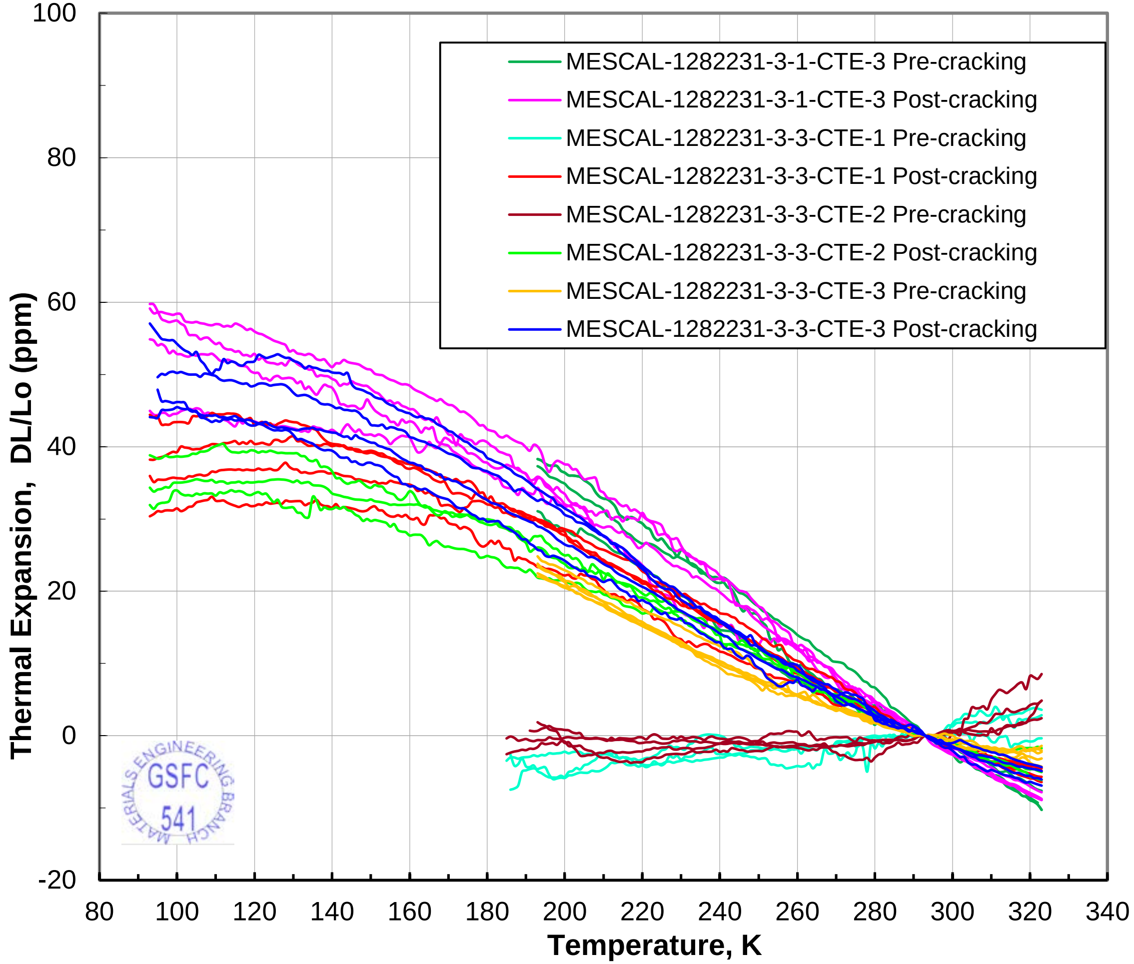


After Thermal Cycle to 93 K

Tensile Test Results

A closer looked at apparent cracking

- Coupons 1282231-3-3-CTE-1 and CTE-2
  - Two coupons from same panel
  - the pre-cracking thermal expansion is lower than the post-cracking thermal expansion.
  - Little difference between the pre- and post- cracking thermal expansion for the other 4 coupons.
  - Post Cracking behavior is the basis for CTE results, and those are still low
- Coupons 1282231-3-1 CTE-3 and 1282231-3-3 CTE-3
  - Two coupons from different panels
  - AFP processed at 21 and 27 ^{0}C
  - Little difference in pre- and post-cracking behavior



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Conclusions

- This work shows high stiffness composite laminates can be processed with AFP technology, and meet science instrument requirements for high stiffness and low CTE
  - AFP processed panels tensile moduli were shown within 6% of hand laid up panels – regardless of processing parameters -
  - AFP processed panels CTEs were shown to be near-zero CTE, the same as hand laid up panels – regardless of processing parameters -
  - AFP processed panels strength values were less than hand laid up composite laminated panels
    - Processing where heat is applied during material and laminate processing can minimize this strength difference
    - Testing showed the lamina tensile strength was reduced by 17% compared to hand laid up panels

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