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# Ceramic Matrix Composite Materials Guidelines for Aircraft Design and Certification

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JAMS 2019 Technical Review

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# Ceramic Matrix Composite Materials

## Guidelines for Aircraft Design and Certification

- Motivation and Key Issues
  - Expanded use of CMCs in engine and other hot section applications
  - CMCs require their own set of rules separate from more established PMCs
  - No “fully approved” data in CMH-17
  - Similar complexity to PMCs in terms of anisotropy, fiber architecture, high strength/stiffness fibers, and production process sensitivity and variability, they are also different in many ways such as:
    - Composite constituents
    - Degradation, damage, and failure mechanisms
    - High temperature life predictions
    - High temperature bonding challenges
    - NDI challenges
    - Repairability

# Development of Qualification Program

- **Technical Monitor:** Ahmet Oztekin
- **NIAR Contacts:** John Tomblin, Rachael Andrulonis, Matt Opliger
- **Industry Partners:** Axiom Materials (prepreg), AC&A (panel), 3M (fiber and fabric), several steering committee members
- **Overall Goals**
  - Primary goal: To develop a framework for the qualification of new and innovative composite material systems including guidelines and recommendations for their characterization, testing, design and utilization.
  - Secondary goal: To transition the test data and guidelines generated in this program into shared databases, such as CMH-17.

# Technical Approach

- Develop a framework to advance CMC materials into the aerospace industry.
- Utilize the experience and framework of the NCAMP composite program as an example of process sensitive material characterization.
- Assess the validity with equivalency testing.

SURVEY

TASK 1:  
Establish  
Steering  
Committee

**December 2016**

TASK 2:  
Develop  
Qualification  
Framework

**TASK 3:  
Validate  
framework  
with selected  
CMC material**

**TASK 4:  
Establish  
statistical  
guidelines**

TASK 5:  
Transition  
- Material  
property data  
- Guidelines

**November 2019**

# Task 1: Steering Committee

- Steering committee formed with interested individuals
- Kick-off meeting was held in December 2016, Monthly meetings
- Collaboration with CMH-17
- Includes participants from industry (Pratt & Whitney, Free Form Fibers, Honeywell, Rolls Royce, Boeing, GE, 3M) and government (NASA, AFRL, FAA)
- Review and provide feedback on qualification plan, documents and resulting data
  - Overall test plan
  - Material specification
  - Process specification
  - Pedigree/documentation
  - Data
  - Statistical analyses

# NCAMP Portal

- All members of the Steering Committee have access
- Monthly meeting charts
- Documents for review
- Related research

The screenshot displays the NCAMP Portal website. At the top, it features the NIAR logo and the text "WICHITA STATE UNIVERSITY NATIONAL INSTITUTE FOR AVIATION RESEARCH". A navigation menu includes links for HOME, CONTACT, DOCUMENTS FOR REVIEW, SCHEDULE, FAQ, NASA REPORTS, PBAM, CMC, Adhesive, Repair, and Advanced Fiber. The date "Thursday, January 18, 2018" is shown, along with a search bar containing "CMC".

The main content area is titled "CMC Qualification Framework Documents" and contains a table with the following data:

Title	Owner	Category	Modified Date
Test Plan Comments and Notes (9/21/2017)	Rachael Andrulonis		9/21/2017
Padings Checklist	Rachael Andrulonis		8/16/2017
CMC Qual Test Plan (8/10/2017)	Rachael Andrulonis		8/10/2017
NCAMP Equivalency Flowchart	Rachael Andrulonis		7/19/2017
NCAMP Qualification Flowchart	Rachael Andrulonis		7/19/2017
CMC Qual Test Matrix - updated 4/19/2017	Rachael Andrulonis		4/20/2017
CMC Qual Test Matrix - for review	Rachael Andrulonis		2/28/2017

Below this table is a section titled "Related Research" with another table:

Title	Owner	Category	Modified Date
CMC evaluation for Turbine Engines (NASA Glenn Research)	Rachael Andrulonis		5/17/2017
CMC Oxidation & Corrosion Study by NASA Glenn Research	Rachael Andrulonis		5/17/2017
CMC Presentation by John Lincoln et al	Rachael Andrulonis		5/17/2017
3M Nextel Fibers & Fabrics Brochure	Rachael Andrulonis		5/17/2017
GenCorp - CMC FAA Paper	Rachael Andrulonis		5/17/2017
GenCorp - CMC FAA Certification Presentation	Rachael Andrulonis		5/17/2017

<http://www.niar.wichita.edu/ncampportal/CMC/tabid/177/Default.aspx>

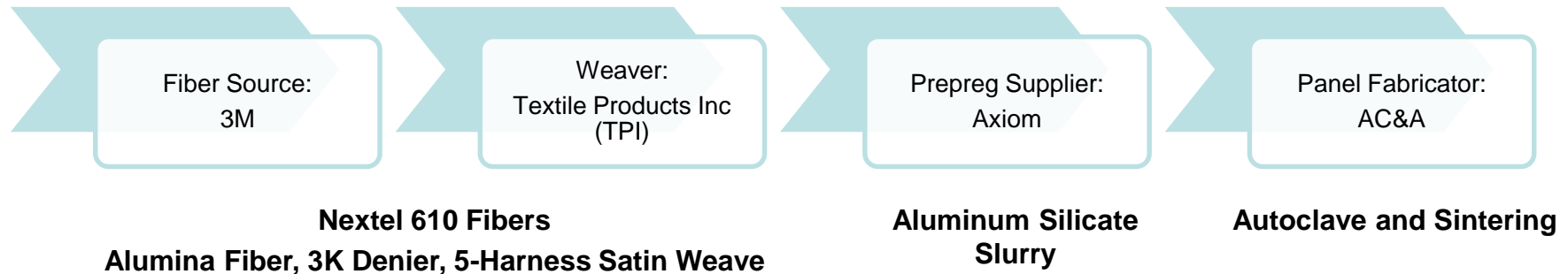
# Task 2: Development of Qualification Program

*GOAL: Generate the framework for a qualification test program including material and process specifications, test matrices, and documentation requirements.*

## Objectives:

- Select an established CMC material and process to initially develop this framework. The material will be selected with input from the steering committee.
- Determine the critical process parameters and how they affect material properties.
- Address quality aspects of the selected CMC process and the framework for a quality assurance program.
- Draft material and process specifications for selected CMC material. *These will be very specific –material, material supplier, processing.*
- Develop CMC test matrix including required physical and mechanical data.
- Generate substantial mechanical property test data necessary for development of statistical guidelines using accepted test standards for CMC materials.

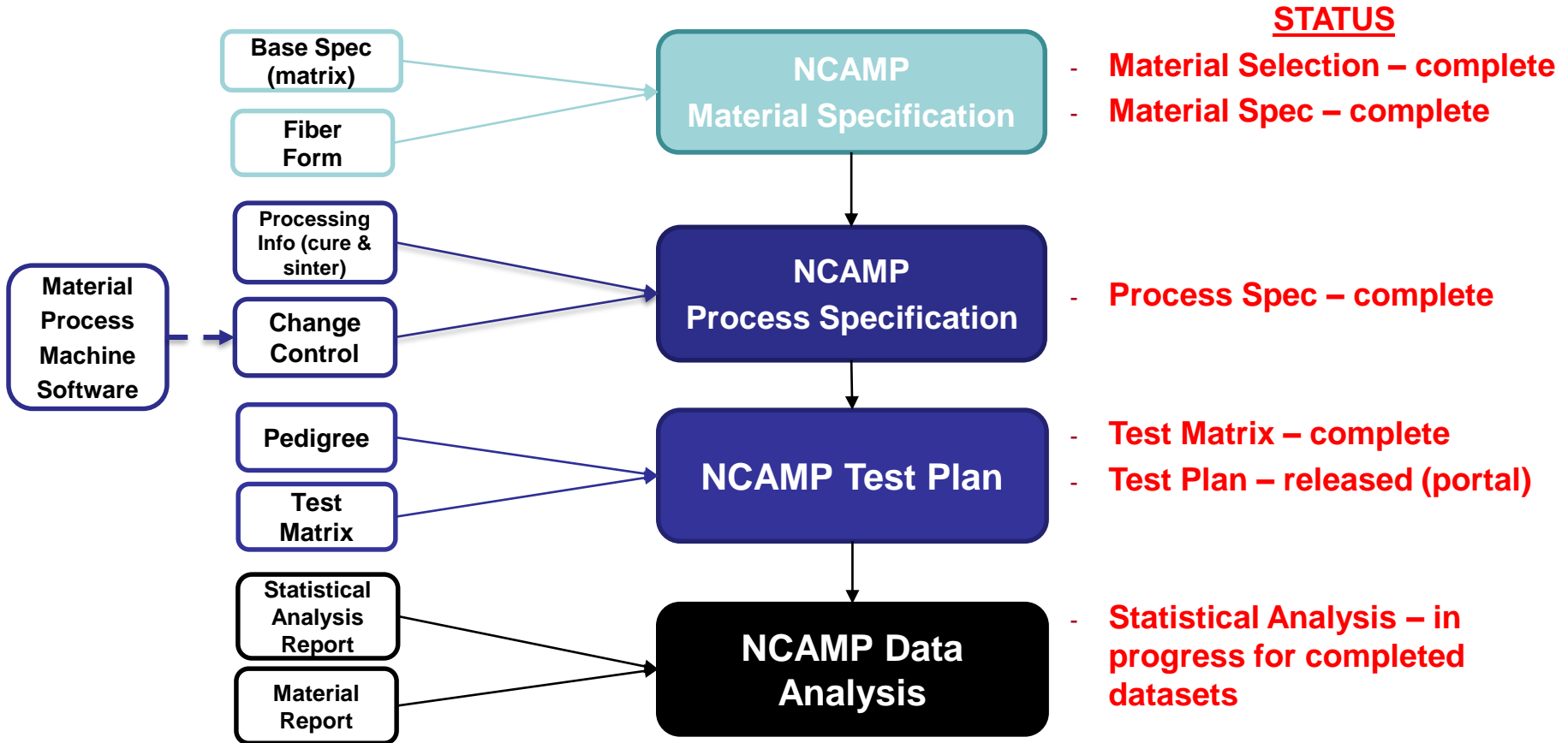
# Material Selection and Process



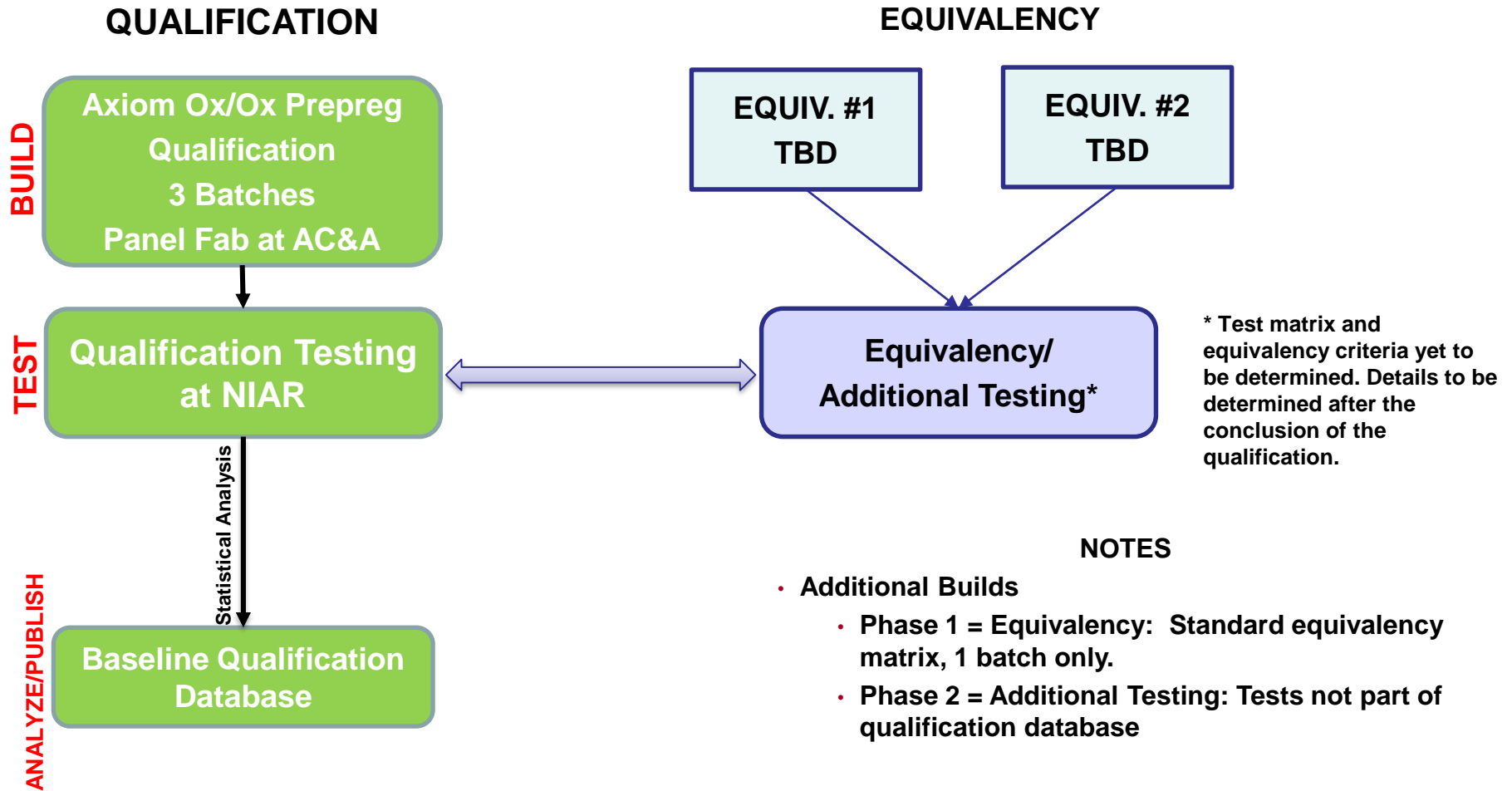
- **Prepreg production is complete**
- **Initial panel fabrication for 3 batch qualification is complete**
- **Some additional panels are being made due to quality issues with some qualification panels from the 3rd batch.**
- **Panel fabrication for prepreg cold storage life and out-time verification is near completion**



# Qualification Documentation



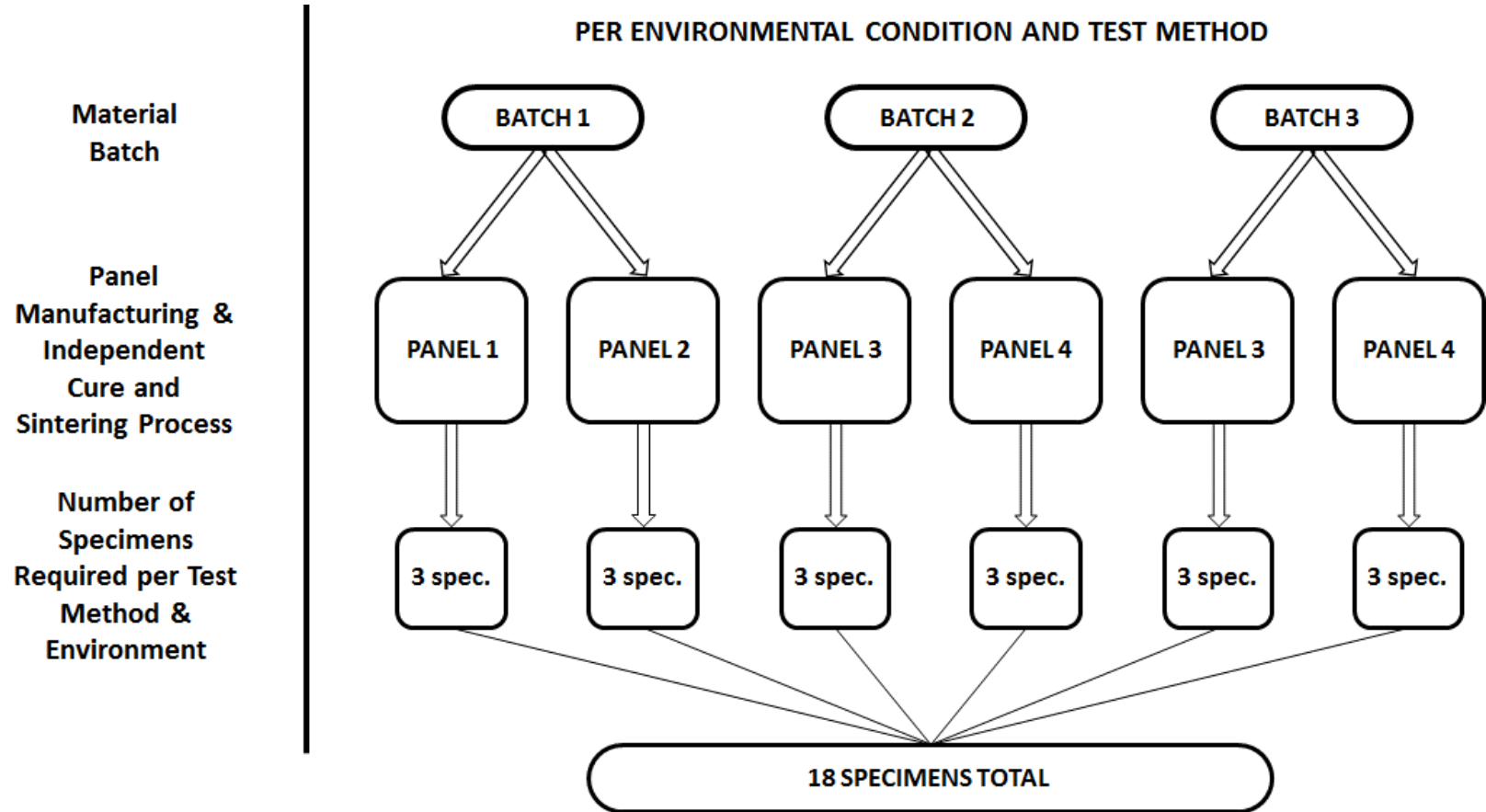
# Qualification Program



# Test Plan Overview

- Resources:
  - Steering Committee
  - PMC NCAMP test matrix
  - CMH-17 Volume 1 and 5
  - DOT/FAA/AR-03/19
  - DOT/FAA/AR-06/10
  - DOT/FAA/AR-02/110
- Selected property and/or conditions for preliminary studies

# Process Definition



# Cured/Sintered Physical and Thermal Tests – Test Matrix

Property	Test Method (See Note 1)	Min Replicates per Panel
NDI by Ultrasonic Through Transmission (C-Scan), Thermography, or Radiography (CT Scan)	(See Note 2)	1
Cured/Sintered Ply Thickness	ASTM D3171 (Method II)	All data from mechanical test specimens
Fiber Volume, % by Volume	ASTM D3171 (Method II) (See Note 3)	3
Matrix Volume, % by Volume	ASTM D3171 (Method II) (See Note 4)	3
Cured/Sintered Matrix Density (See Note 5)	ASTM C373	3 (Total per Batch)
Cured/Sintered Composite Density (See Note 6)	ASTM C373	3
Void/Porous Content	ASTM C373	3
Specific Heat (See Note 7)	ASTM E1269	3 (Total per Batch)
Thermal Conductivity (Diffusivity), Measured in x, y, and z directions (See Note 8)	ASTM E1461	3 (See Note 9)
Thermal Expansion, Measured in x, y, and z directions (See Note 8)	ASTM E228	3 (See Note 9)

# Cured/Sintered Physical and Thermal Tests – Status

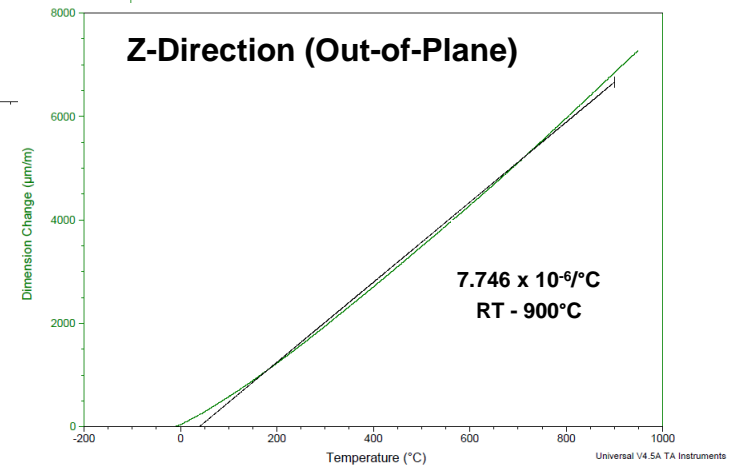
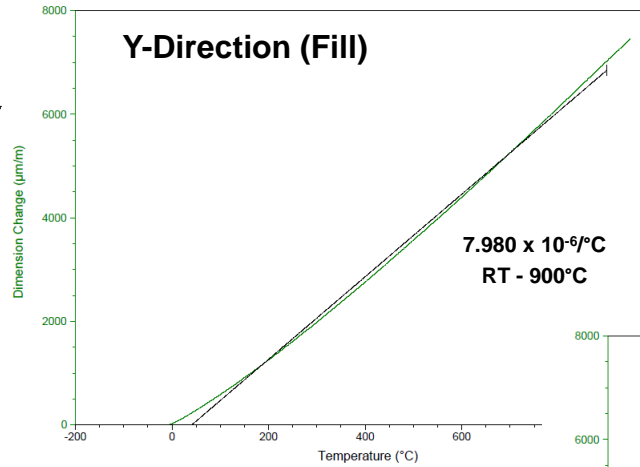
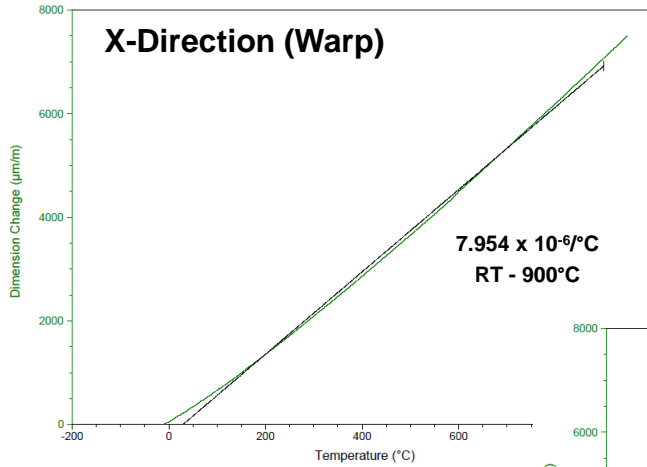
QUALIFICATION REQUIREMENTS	TEST METHOD	Min Replicates per Panel Required	TOTAL QTY RQD	QTY TESTED	Percent Complete
			735	591	80%
NDI by Thermography		1	96	78	81%
Cured/Sintered Ply Thickness					
Fiber Volume, % by Volume	ASTM D3171 (Method II)	3	288	234	81%
Matrix Volume, % by Volume					
Cured/Sintered Matrix Density					
Cured/Sintered Composite Density	ASTM C373	3	288	234	81%
Void/Porous Content					
Specific Heat	ASTM E1269	3 (Total per Batch)	9	9	100%
Thermal Conductivity (Diffusivity), Measured in x, y, and z directions	ASTM E1461	3 (Total per Batch, per Direction)	27	9	33%
Thermal Expansion, Measured in x, y, and z directions	ASTM E228	3 (Total per Batch, per Direction)	27	27	100%

	Tests complete
	N/A
	Additional tests required due to panel quality issues

# Cured/Sintered Physical Tests – Results

Prepreg Batch	Statistic	Bulk Density $B$ [g/cm <sup>3</sup> ]	Apparent Porosity $P$ [%]	Matrix Weight $W_m$ [%]	Fiber Volume $V_f$ [%]	Matrix Volume $V_m$ [%]
A	Mean	2.6803	28.1077	42.81	39.31	32.584
	Minimum	2.6415	26.9020	41.11	36.94	31.677
	Maximum	2.7271	29.0032	45.46	41.11	34.65
	C.V. (%)	0.7679	1.6666	1.97	1.94	1.705
	No. of Specimens	78	78	78	78	78
B	Mean	2.7188	27.3840	39.84	41.95	30.667
	Minimum	2.6289	26.1156	34.94	38.77	27.252
	Maximum	2.7665	29.7926	43.38	45.98	33.864
	C.V. (%)	0.9828	2.5408	5.35	4.10	4.90
	No. of Specimens	78	78	78	78	78
C	Mean	2.6207	29.5918	38.69	41.24	29.169
	Minimum	2.4790	26.4612	32.07	35.11	25.036
	Maximum	2.7168	33.0816	45.01	46.16	32.216
	C.V. (%)	2.8802	7.0647	8.11	7.24	5.55
	No. of Specimens	78	78	78	78	78

# Coefficient of Thermal Expansion – Results





# Lamina Level Mechanical Tests – Test Matrix

Layup	Test Type and Direction (See Note 9)	Property	Test Method	Number of Batches x No. of Panels x No. of Specimens	
				Test Temperature	
				RTD	ETD
[0] <sub>5S</sub>	Warp Tension (See Notes 1, 7, 8, and 10)	Strength, Modulus, and Poisson's Ratio (RTD Only)	ASTM C1275 (RTD) ASTM C1359 (ETD)	3x2x3	3x2x3
[90] <sub>5S</sub>	Fill Tension (See Notes 1, 7, 8, and 10)	Strength and Modulus	ASTM C1275 (RTD) ASTM C1359 (ETD)	3x2x3	3x2x3
[0] <sub>6S</sub>	Warp Compression (See Notes 2, 7, 8, and 10)	Strength and Modulus	ASTM C1358	3x2x3	3x2x3
[90] <sub>6S</sub>	Fill Compression (See Notes 2, 7, 8, and 10)	Strength and Modulus	ASTM C1358	3x2x3	3x2x3
[45/-45] <sub>2S</sub>	In-Plane Shear (45/-45 Tension) (See Notes 3 and 8)	Strength and Modulus (RTD Only)	ASTM D3518	3x2x3	3x2x3
[0] <sub>7S</sub>	In-Plane Shear (V-Notch Shear) (See Notes 4 and 8)	Strength and Modulus	ASTM D5379	3x2x3	
[0] <sub>7S</sub>	Interlaminar Shear (Double-Notch Shear) (See Note 5)	Strength	ASTM C1292 (RTD) ASTM C1425 (ETD)	3x2x3	3x2x3
[0] <sub>28</sub>	Interlaminar Shear (Short-Beam Strength) (See Note 6)	Strength	ASTM D2344	3x2x3	

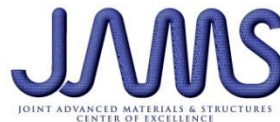
RTD: 70±10°F,  
ETD: 1650±5°F



# Lamina Level Mechanical Tests – Status

QUALIFICATION REQUIREMENTS	TEST METHOD	Condition	RTD						ETD						TOTAL QTY RQD	QTY TESTED	Percent Complete
		Test Temperature (°F)	70						1650								
													252	192	76%		
<b>Tensile Properties</b>	ASTM C1275 (RTD) ASTM C1359 (ETD)																
Tensile Strength		Batch	A		B		C		A		B		C				
Modulus		Warp: [0]5S	6	6	6	6	6	6	6	6	6	6	6	6	36	36	100%
Poisson's Ratio, RTD and [0] only		Fill: [90]5S	6	6	6	6	6	6	6	6	6	6	6	6	36	36	100%
<b>Compressive Properties</b>	ASTM C1358																
		Batch	A		B		C		A		B		C				
Compressive Strength		Warp: [0]6S	6	6	6	6	6	6		6		6		6	36	18	50%
Compressive Modulus		Fill: [90]6S	6	6	6	6	6	6		6		6		6	36	18	50%
<b>In-Plane Shear Properties - 45/-45 Tension</b>	ASTM D3518																
Shear Strength		Batch	A		B		C		A		B		C				
Shear Modulus [RTD only]		[45/-45]2S	3	6	6	6	6	6	3	6	6	6	6	6	36	30	83%
<b>In-Plane Shear Properties - V-Notch Shear</b>	ASTM D5379																
Shear Strength		Batch	A		B		C		A		B		C				
Shear Modulus		[0]7S	6	6	6	6	6	6							18	18	100%

Tests complete  
 N/A  
 Additional tests required due to panel quality issues



# Lamina Level Mechanical Tests – Status (Cont.)

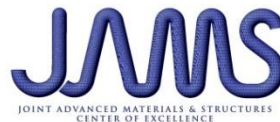
Interlaminar Shear Properties - Double Notch Shear	ASTM C1292 (RTD)													
	ASTM C1425 (ETD)	Batch	A		B		C		A	B	C			
Shear Strength		[0]75	6	6	6	6	6	6	6	6	6	36	18	50%
Interlaminar Shear Properties - Short- Beam Strength	ASTM D2344													
		Batch	A		B		C		A	B	C			
Shear Strength		[0]28	6	6	6	6	6	6				18	18	100%

	Tests complete
	N/A
	Additional tests required due to panel quality issues

# Laminate Level Mechanical Tests – Test Matrix

Layup (See Note 12)	Test Type and Direction (See Note 10)	Property	Test Method	Number of Batches x No. of Panels x No. of Specimens	
				Test Temperature	
				RTD	ETD
[0] <sub>7S</sub>	Flexure (See Notes 1, 9, and 11)	Strength and Modulus	ASTM C1341	3x2x3	
[0] <sub>10</sub>	Interlaminar Tension (Trans-Thickness/ Flatwise Tension) (See Note 2)	Strength	C1468	3x2x3	
[0/90] <sub>5</sub>	Interlaminar Tension (Trans-Thickness/ Flatwise Tension) (See Note 2)	Strength	C1468	1x1x6	
[0/90] <sub>14</sub>	Interlaminar Shear (Short-Beam Strength)	Strength	ASTM D2344	1x1x6	
[45/0/-45/90/-45/90] <sub>S</sub>	Unnotched Tension (See Notes 3, 9, and 11)	Strength and Modulus	ASTM C1275 (RTD) ASTM C1359 (ETD)	3x2x3	3x2x3
[45/0/-45/90/-45/90] <sub>S</sub>	Unnotched Compression (See Notes 4, 9, and 11)	Strength and Modulus	ASTM C1358	3x2x3	3x2x3
[45/0/-45/90] <sub>2S</sub>	Open-Hole Compression (See Notes 5 and 11)	Strength	ASTM D6484	3x2x3	3x2x3
[45/0/-45/90/-45/90] <sub>S</sub>	Open-Hole Tension (See Notes 6 and 11)	Strength	ASTM D5766	3x2x3	3x2x3
[45/0/-45/90/-45/90] <sub>S</sub>	Filled-Hole Tension (See Notes 7 and 11)	Strength	ASTM D6742	3x2x3	3x2x3
[45/0/-45/90/-45/90] <sub>S</sub>	Single Shear Bearing (See Note 11)	Strength	ASTM D5961 (Procedure C)	3x2x3	3x2x3
[45/0/-45/90/-45/90] <sub>S</sub>	Tension After Impact (See Notes 8 and 11)	Strength	ASTM D7136 ASTM D5766	1x2x3	1x2x3

RTD: 70±10°F,  
ETD: 1650±5°F

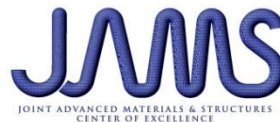


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# Laminate Level Mechanical Tests – Status

QUALIFICATION REQUIREMENTS	TEST METHOD	Condition	RTD						ETD						TOTAL QTY RQD	QTY TESTED	Percent Complete
		Test Temperature (°F)	70						1650								
												291	207	71%			
Flexure	ASTM C1341																
Strength		Batch	A	B	C	A	B	C									
Modulus		[0]7S	6	6	6	6	6	6							18	18	100%
Interlaminar Tension (Trans-thickness/flatwise tension)	ASTM C1468																
		Batch	A	B	C	A	B	C									
		[0]10	6	6	6	6	6	6							18	18	100%
Strength		[0/90]5	6	6										6	6	100%	
Interlaminar Shear - Short Beam Strength	ASTM D2344																
		Batch	A	B	C	A	B	C									
Strength		[0/90]14	6	6											6	6	100%
Unnotched Tension	ASTM C1275 (RTD) ASTM C1359 (ETD)																
Strength		Batch	A	B	C	A	B	C									
Modulus		[45/0/-45/90/-45/90]S	6	6	6	6	6	6	6	6	6	6	6	6	36	36	100%

Tests complete  
 N/A  
 Additional tests required due to panel quality issues



# Laminate Level Mechanical Tests – Status (Cont.)

<b>Unnotched Compression</b>	ASTM C1358																
Strength		Batch	A		B		C		A		B		C				
Modulus		[45/0/-45/90/-45/90]S	6	6	6	6	6	6		6		6		6	36	18	50%
<b>Open-Hole Compression</b>	ASTM D6484																
Strength		Batch	A		B		C		A		B		C				
		[45/0/-45/90]2S	6	6	6	6	6	6		6		6		6	36	18	50%
<b>Open-Hole Tension</b>	ASTM D5766																
Strength		Batch	A		B		C		A		B		C				
		[45/0/-45/90/-45/90]S	6	6	6	6	6	6	6	6	6	6	6	6	36	36	100%
<b>Filled-Hole Tension</b>	ASTM D6742																
Strength		Batch	A		B		C		A		B		C				
		[45/0/-45/90/-45/90]S	6	6	6	6	6	6	6	6	6	6	6	6	36	36	100%
<b>Single-Shear Bearing</b>	ASTM D5961 (Procedure C)																
Strength		Batch	A		B		C		A		B		C				
		[45/0/-45/90/-45/90]S	6	6	3	3	6	6							15	15	100%

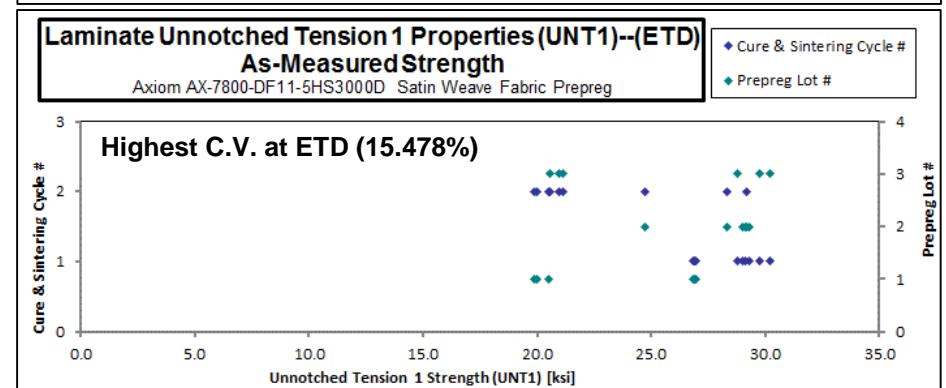
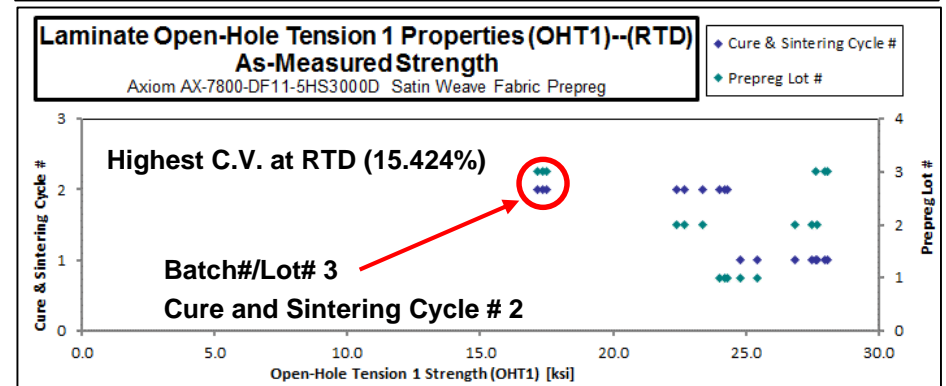
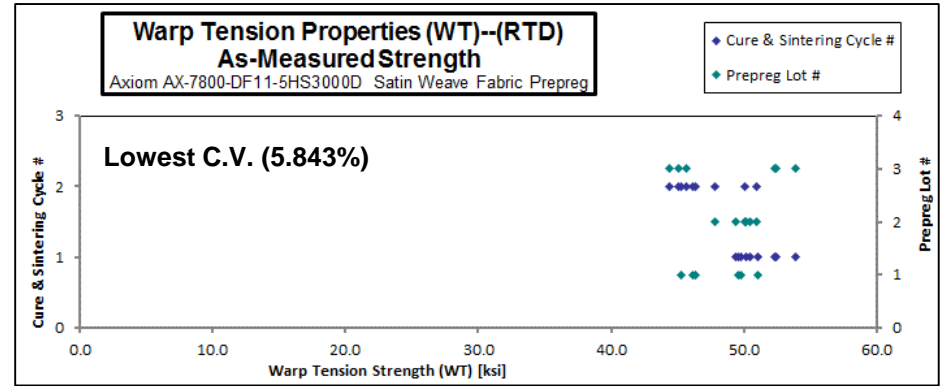
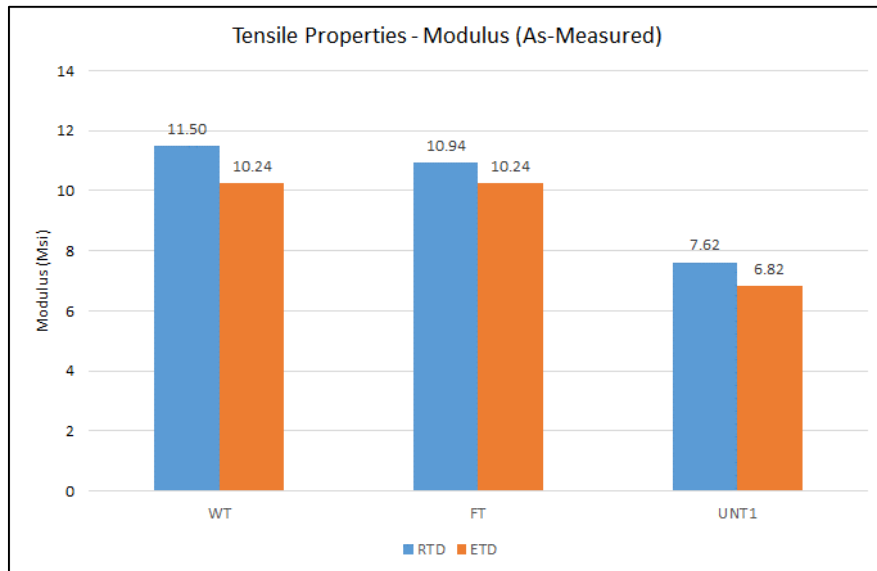
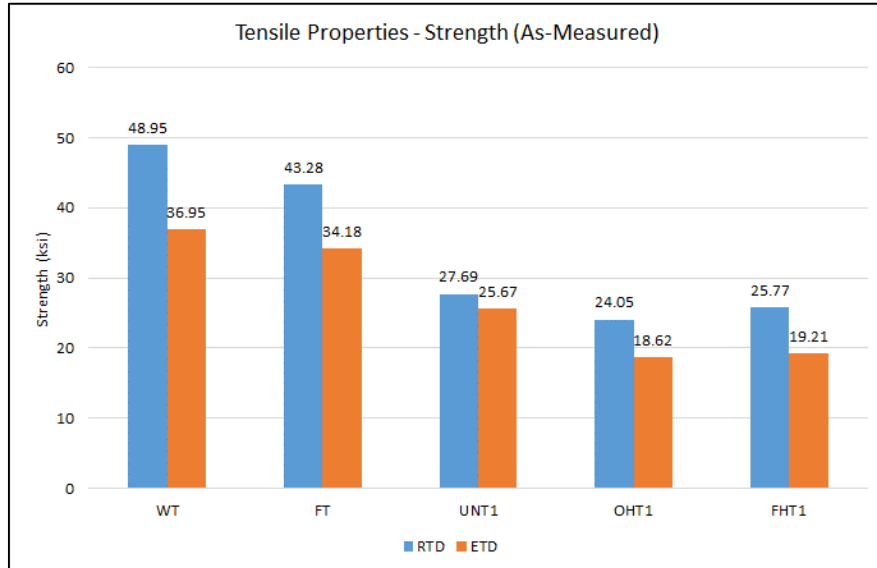
	Tests complete
	N/A
	Additional tests required due to panel quality issues

# Laminate Level Mechanical Tests – Status (Cont.)

Double-Shear Bearing	ASTM D5961 (Procedure A)	Batch	A			B			C			36	0	0%
Strength		[45/0/-45/90/-45/90]S	6	6	6	6	6	6	6	6				
Tension After Impact	ASTM D7136 ASTM D5766	Batch	D			D			D			12	0	0%
Strength		[45/0/-45/90/-45/90]S	6			6								

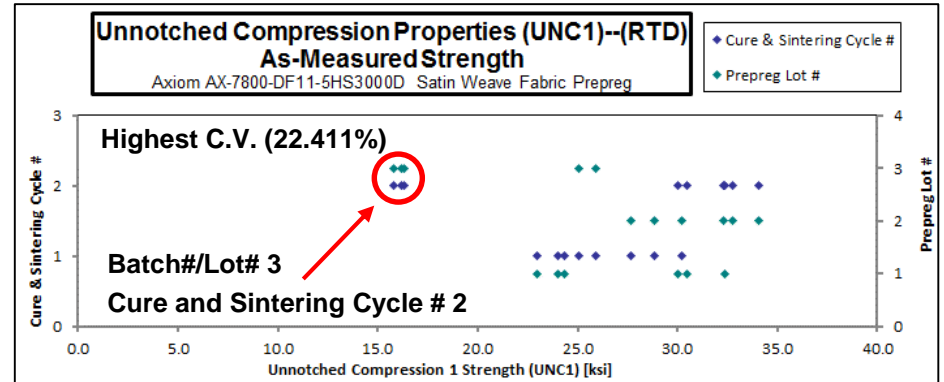
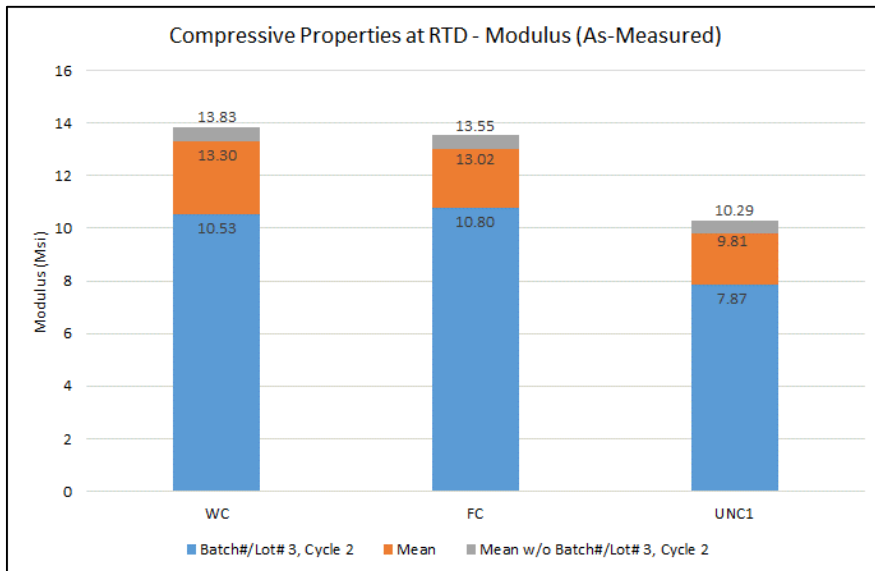
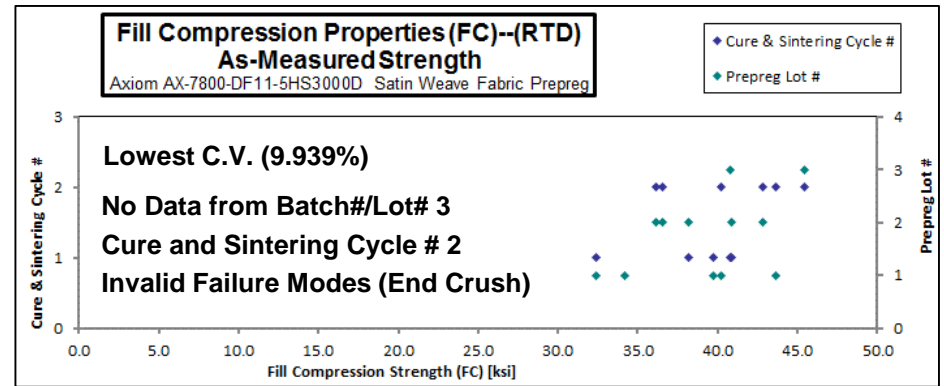
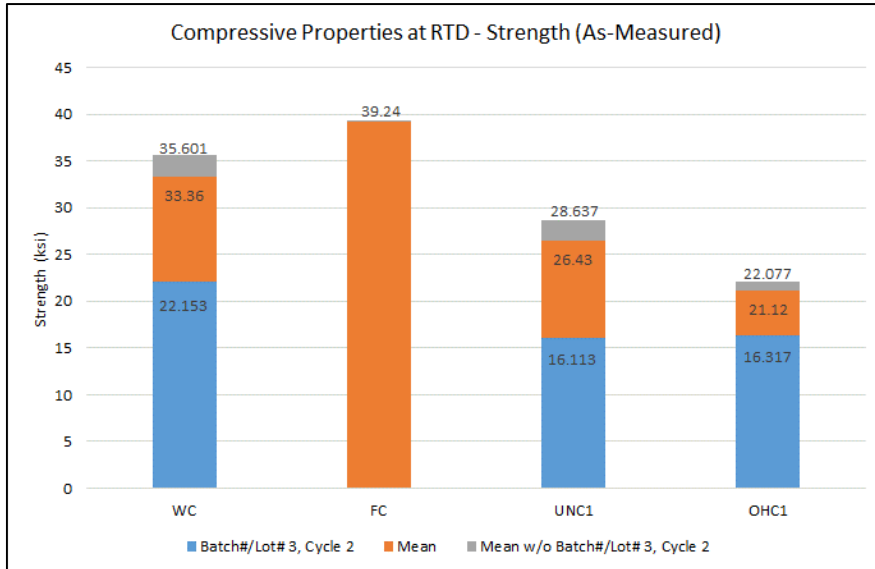
- Tests complete
- N/A
- Additional tests required due to panel quality issues

# In-Plane Tensile Properties – Results

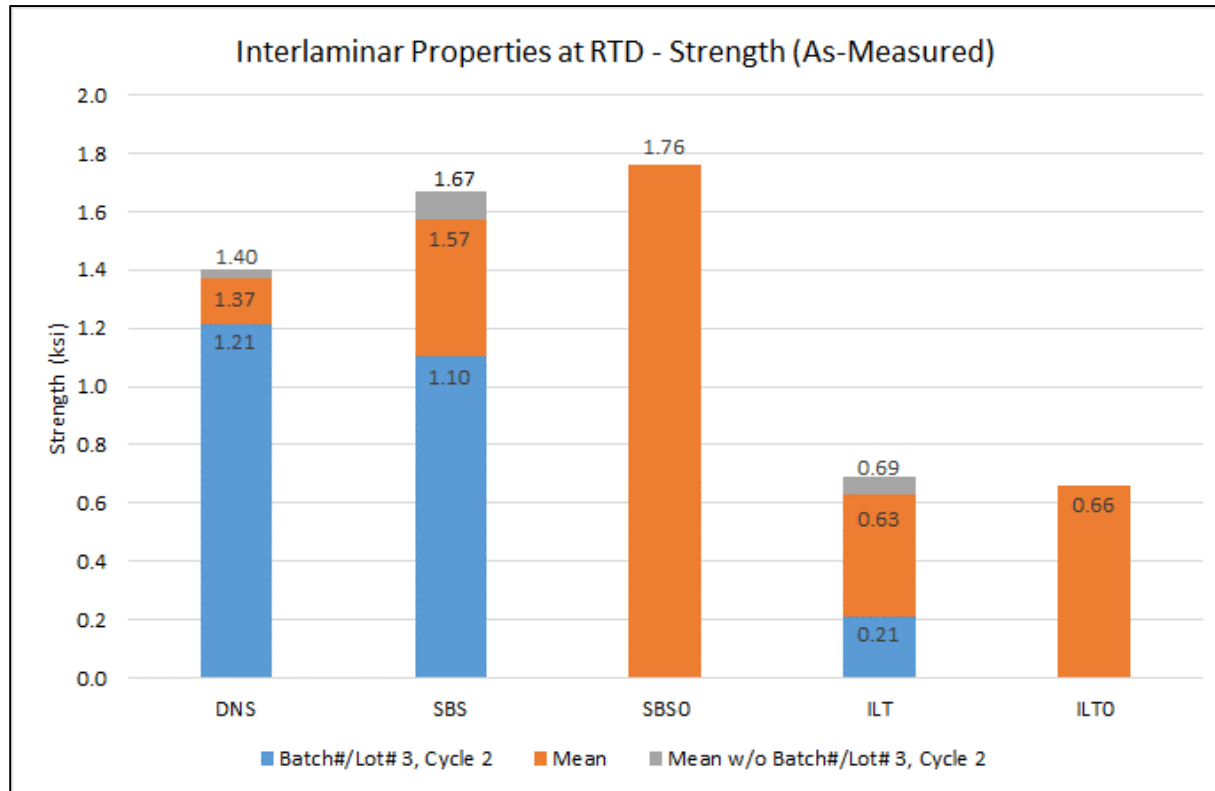




# In-Plane Compressive Properties – Results



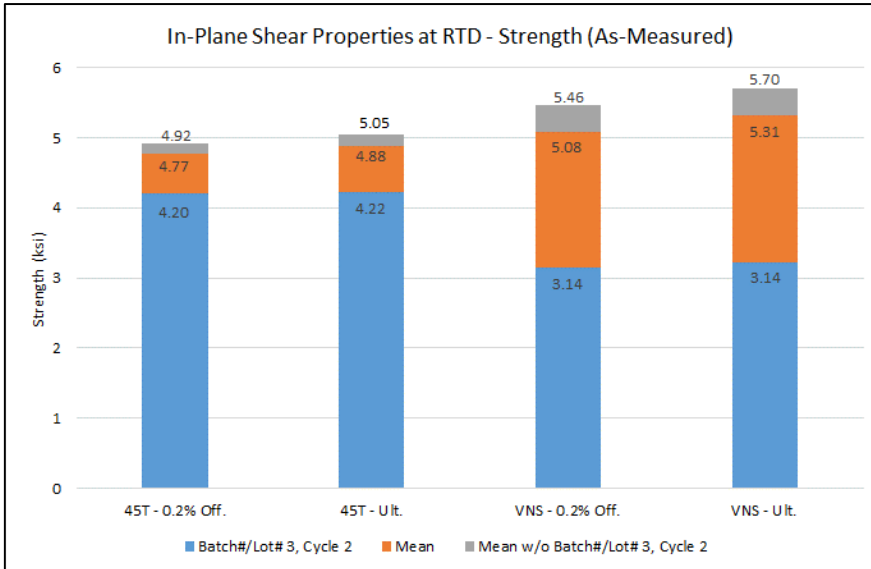
# Interlaminar Properties – Results



C.V. for the interlaminar properties

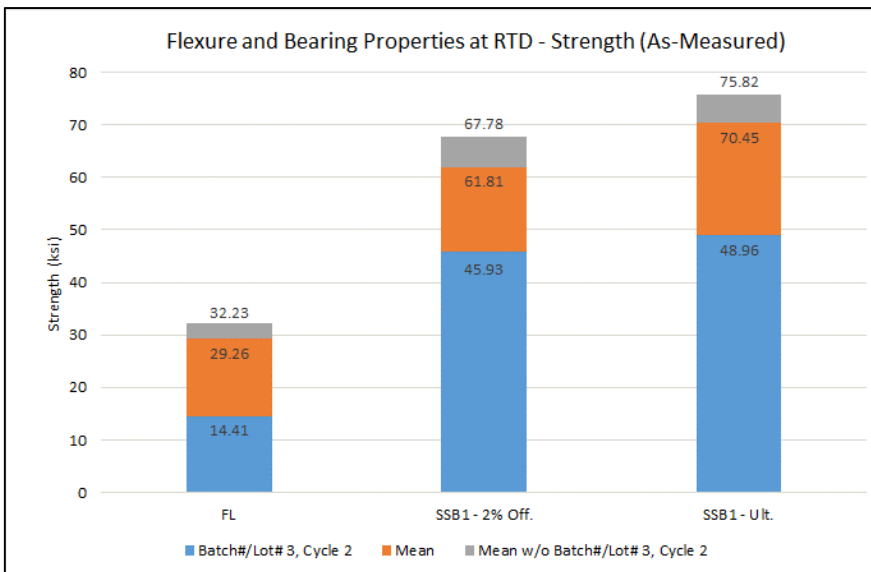
- DNS: 19.015%
- SBS: 18.663%
- SBS0: 2.105%
- ILT: 27.416%
- ILT0: 6.464%

# Other Properties – Results



C.V. for the interlaminar properties

- 45T - 0.2% Off.: 13.080%
- 45T - Ult.: 13.137%
- VNS - 0.2% Off. : 29.600%
- VNS - Ult.: 29.365%
- FL: 27.377%
- SSB1 - 2% Off.: 17.739
- SSB1 - Ult.: 16.620



# Other Test Types Included

- Fluid Sensitivity Tests
  - Exposure to fluids such as fuel, oils, sea water, deicing fluid, rain water, tap water, and engine cleaner
  - Short beam strength testing at room temperature for fluids
  - Short beam strength testing at room temperature for selected fluids after post-immersion conditioning at 1650°F for a minimum of 60 minutes
- Cold Storage and Out-Time Verification
  - Refrigerator Storage Intervals: as manufactured, 6 months and 12 months
  - Out-Time Intervals: 1 day, 7 days, 14 days, 28 days, and 42 days
  - Physical Tests: Volatile Content / Mass Loss, Flow, Tack and Drape
  - Mechanical Tests: Fill Tension

# Task 4: Guidelines and Recommendations

*GOAL: To provide guidelines to industry for the collection of statistically meaningful critical data that designers need to utilize CMC materials potentially including:*

- Creation of a shared CMC database including test data, material and process specifications and statistical analysis methods.
- Development of handbook data and guidelines (i.e., CMH-17).
- Coordinate with other standards and specification organizations to develop specifications from this program.

# Overall Program Status

	Activity	Target Date	Milestone / Deliverable	Complete?
1.2	Industry Steering Committee - Establish group of participants - Create online portal for document sharing and data repository	12/15/2016	Milestone	✓
1.3	Preliminary drafts of qualification framework - Material and process specifications - Test plan - Conformity documentation	6/30/2017	Deliverable	✓
1.4	Qualification Audit	11/10/2017	Milestone	✓

# Overall Program Status

	Activity	Target Date	Milestone / Deliverable	Complete?
1.1	Trial / Screening Studies (ongoing) - Perform physical and mechanical tests to assist in final test matrix development and selection of machining and NDI methods - Present data to FAA, Industry Steering Committee, NCAMP Partners	1/15/2018	Milestone	✓
1.2	Qualification Material - Site audit complete (scheduled for 11/7-11/8/2017) - Initial set of qualification panels built and delivered to NIAR - Additional panels being built replace poor quality panels from material batch 3.	7/31/2019	Milestone	Panels in progress
1.3	Qualification Testing - Perform physical, thermal and mechanical testing on qualification panels - Generate test data for qualification program	9/30/2019	Milestone	Testing in progress
1.4	Develop Statistical Guidelines based on qualification data	10/31/2019	Milestone	Statistical analysis in progress
1.5	NCAMP Reports on Qualification Data - Material technical report - Statistical analysis technical report	10/31/2019	Deliverable	
1.6	CMH-17 - Submit content, data, and protocols to Composite Materials Handbook 17 (CMH-17)	11/30/2019	Deliverable	
1.7	Final Report - Final Technical Report on the Guidelines for CMC Qualification	11/30/2019	Deliverable	

# Looking forward

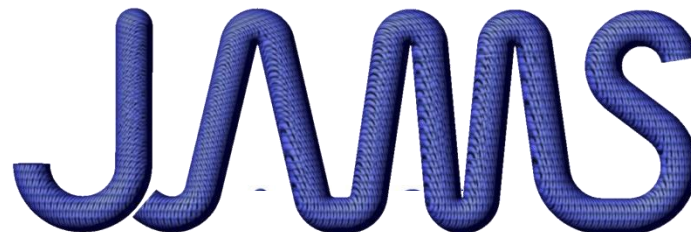
- Benefit to Aviation
  - Publically available CMC data linked to M&P specs
  - Addition to CMH-17 handbook
  - CMC – PCD and process spec guidelines
- Future needs
  - Validate qualification data with equivalencies
  - Trial studies needed:
    - Processing effects on CMCs
    - SiC/SiC or C/SiC composites
    - Effects of thermal and environmental barrier coating



# Questions?

Don't forget to fill out the feedback form  
in your packet or online at  
[www.surveymonkey.com/r/jamsfeedback](http://www.surveymonkey.com/r/jamsfeedback)

Thank you.



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# Backup Slide 1 - Fluid Sensitivity Tests

<u>Extended Contact:</u>	Exposure by Immersion	Post-Immersion Conditioning	Test Condition	Code
ASTM D1655 Jet A Fuel (other jet fuel may be used but its type must be reported)	90 days min. at 70±10°F	Stored per Note 1	70°F	FS11RT
		60 minutes min. at 1650±5°F (See Note 2)	70°F	FS41RT
MIL-PRF-5606 Hydraulic Oil	90 days min. at 70±10°F	Stored per Note 1	70°F	FS12RT
MIL-PRF-6083 Hydraulic Oil	90 days min. at 70±10°F	Stored per Note 1	70°F	FS13RT
MIL-PRF-87257 Hydraulic Oil	90 days min. at 70±10°F	Stored per Note 1	70°F	FS14RT
		60 minutes min. at 1650±5°F (See Note 2)	70°F	FS44RT
MIL-PRF-7808 Engine Oil	90 days min. at 70±10°F	Stored per Note 1	70°F	FS15RT
MIL-PRF-23699, Class STD Engine Oil	90 days min. at 70±10°F	Stored per Note 1	70°F	FS16RT
Sea Water (ASTM D1141 or equiv.)	90 days min. at 70±10°F	Stored per Note 1	70°F	FS17RT
		60 minutes min. at 1650±5°F (See Note 2)	70°F	FS47RT
Skydrol LD-4 (SAE AS1241, Type IV, Class 1)	90 days min. at 70±10°F	Stored per Note 1	70°F	FS18RT
		60 minutes min. at 1650±5°F (See Note 2)	70°F	FS48RT
50% DI Water with 50% Skydrol LD-4 (SAE AS1241, Type IV, Class 1)	90 days min. at 70±10°F	Stored per Note 1	70°F	FS19RT
Rain Water (Acidic – pH of 3)	90 days min. at 70±10°F	Stored per Note 1	70°F	FS1ART
Tap Water (Iron Content ≈ 0.3 mg/L)	90 days min. at 70±10°F	Stored per Note 1	70°F	FS1BRT
<u>Short Duration Contact:</u>				
TURCO 4181-L Engine Cleaner	90 minutes min. at 70±10°F	Stored per Note 1	70°F	FS21RT
Polypropylene Glycol Deicer (Type I, SAE AMS 1424)	90 minutes min. at 70±10°F	Stored per Note 1	70°F	FS22RT
		60 minutes min. at 1650±5°F (See Note 2)	70°F	FS53RT
<u>Control Tests:</u>				
Distilled Water	90 days min. at 70±10°F	Stored per Note 1	70°F	FS31RT
Dry	Per section 6.1	Stored per Note 1	70°F	FS32RT
		60 minutes min. at 1650±5°F (See Note 2)	70°F	FS62RT

Note 1: Specimens do not require post-immersion conditioning. Specimens shall be stored inside of a sealed bag at 70±10°F until testing begins.

Note 2: Specimens shall be conditioned for 60 minutes min. at 1650±5°F in air. After specimens have been conditioned, they shall be stored inside of a sealed bag at 70±10°F until testing begins.