Resin Infused Fiber Reinforced Materials Guidelines for Aircraft Design and Certification Process

Federal Aviation Administration

Presented by:

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NATIONAL INSTITUTE FOR AVIATION RESEARCH
Composites & Advanced Materials

JAMS Technical Review

September 29th, 2021

JAMS

Joint Centers of Excellence for Advanced Materials

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

CECAM
center of excellence for composites and advanced materials

Introduction

- Resin Infused Fiber Reinforced Materials Guidelines for Aircraft Design and Certification Process
- **Project Participants**
    - Dr. John Tomblin, Rachael Andrulonis, Royal Lovingfoss, Michelle Man
- **FAA Technical Monitor**
    - Curtis Davies
- **Other FAA Personnel** - Cindy Ashforth
- **Industry Partnerships/Other Collaborations**
    - Solvay, Teijin, Fiber Dynamics, several other industry committee members
- Source of matching contribution – Kansas Aviation Research and Technology

Background

- Motivation and Key Issues
  - Interest in resin infused fiber reinforced composite materials are growing
  - Resin infusion process would be ideal for low volume medium to large scale applications
  - Complex geometric parts as a unitized structure; optimizing production
  - Reduces capital and ongoing cost of large structure manufacturing
  - Easier to manipulate dry reinforcements over tooling
  - Currently there is no resin infused qualification data in NCAMP database or CMH17

Background

- Objective and Scope

  •Primary goal: To develop a framework for the qualification of resin infused fiber reinforced materials 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.

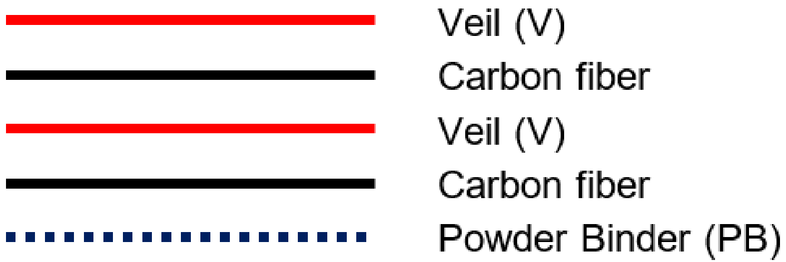
- Approach
  - Survey OEM designers, manufacturers/user and experts on material selection
  - Conduct trials to narrow material selection and determine critical process parameters
  - Set framework for Material Qualification
  - Statistical Analysis Methods
  - Data and Guidelines

Technical Approach

- Committee Review Group established – Industry users, suppliers, FAA
- Material selection narrowed
  - Resin: Solvay PRISM™ EP 2400
  - Reinforcement: Tenax™-E IMS65 Non-Crimp Reinforcement
- Processing Method – VARTM vs RTM
- Trials to determine project needs, challenges, critical process control parameters
  - Set framework for Material Qualification
  - Develop M&P Specifications
  - Develop Mechanical, Physical and Chemical requirements
  - Test data sufficient for developing statistical guidelines

Reinforcement

- Reinforcement: Tenax™-E IMS65 Non-Crimp Reinforcement
- Non Crimp Fabric
  - Biaxial (BA) – carbon fibers in 0°/90° or 90°/0°
  - Bidiagonal (BD) – carbon fibers in +45°/-45° or -45°/+45° (also in ±30° and ±60°)
  - UD (woven with yarn)
- Toughening veil
- Powder binder



Reinforcement – Stitching Techniques

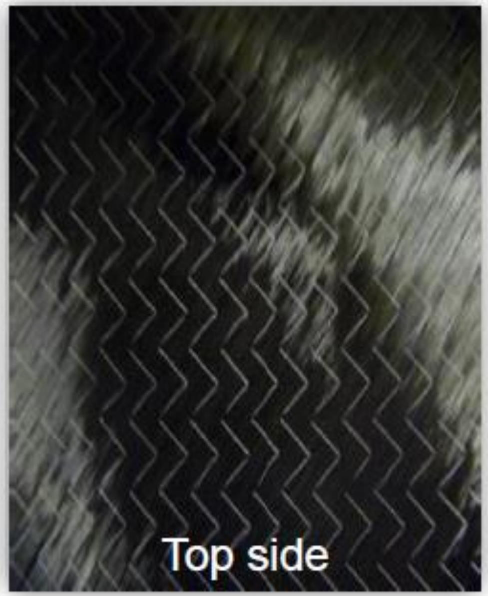
- Pillar Stitch
  - High stability
  - Limited drapeability

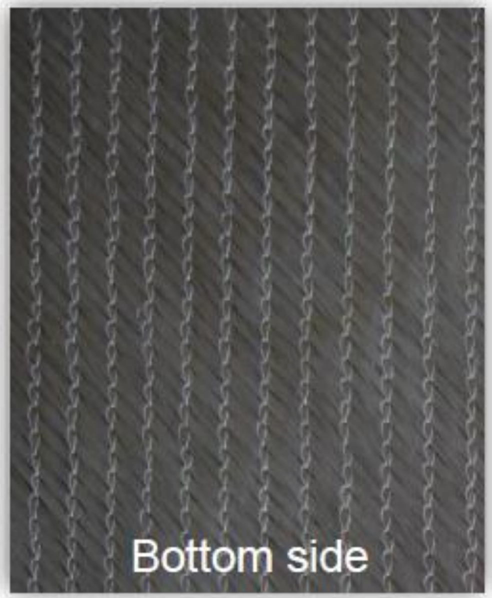
Reinforcement – Stitching Techniques

- Tricot - Pillar Stitch
  - Compromise between performance and drapeability
  - Used in Bidiagonal NCF

Reinforcement – Stitching Techniques

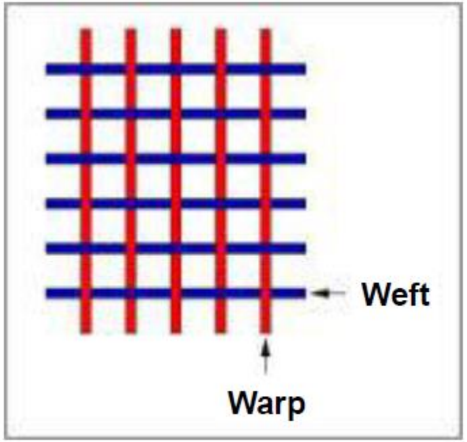
- Tricot Stitch
  - Best drapeability
  - Additional improvements possible – stitching length and loop stitch
  - Used in Biaxial NCF (tricot loop)

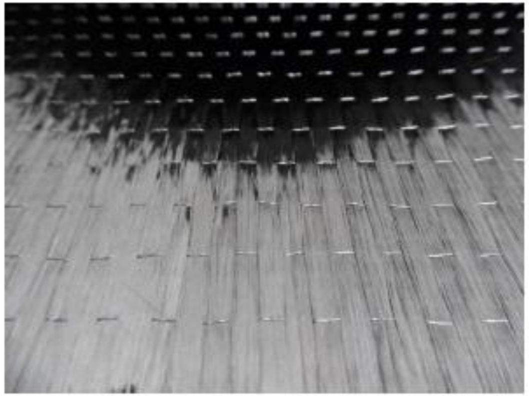




Reinforcement – UD (woven)

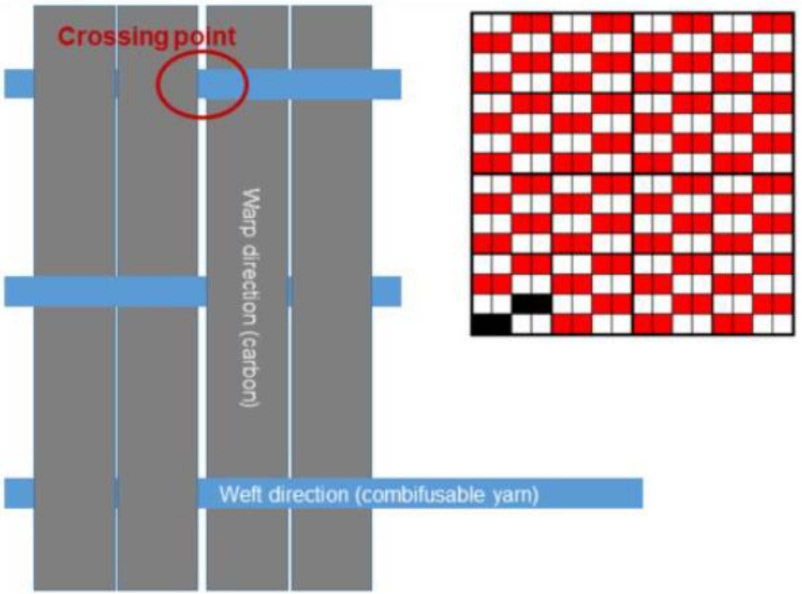
- UD Woven
  - Warp – Carbon fibers
  - Weft – Combi-fuseable yarn woven into the fibers
  - Provide localized reinforcement
  - Veil and Fiber



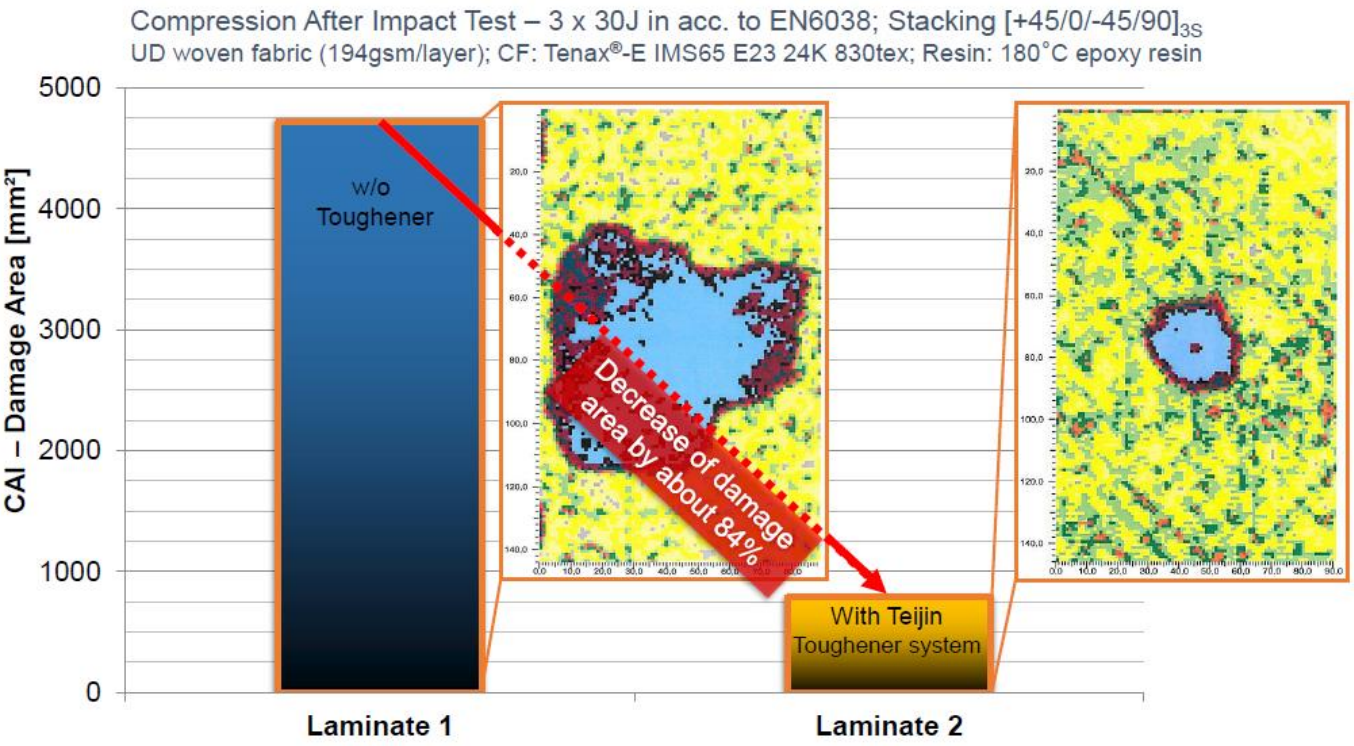


Reinforcement – UD (woven)

- UD Woven
  - Increasing crossing point improves permeability
  - Balance between crossing point and mechanical performance



Effect of Veil



Resin

- Solvay PRISM™ EP 2400
- One-part toughened epoxy resin
- 2 hour cure at 356°F cure
  - Intended service temp >250°F
- Superior toughness, low viscosity, and extended pot-life

Trial Phase

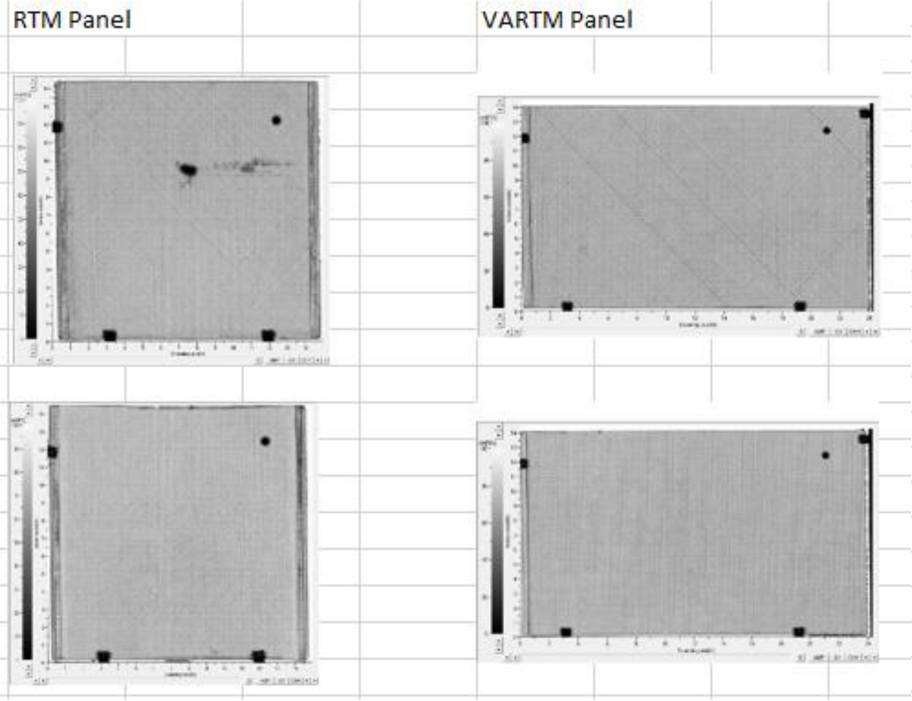
Lamina Table, All test at RTA							
Layup	**Approx Target Thickness (in)**	**# of NCF layers**	**D3039 Tension**	**D6641**	**D3518 In-Plane Shear**	**D2344 Short Beam Shear**	**D790 Flex**
[45/-45]3s	0.087 - 0.090	6	5 (rotated panel)	5*	5		5
[0/90]3s	0.087 - 0.090	6	5	5 in 0 and 5 in 90	5 (rotated panel)		5
[45/-45]6s	0.174 - 0.180	12				5	
[0/90]6s	0.174 - 0.180	12				5	

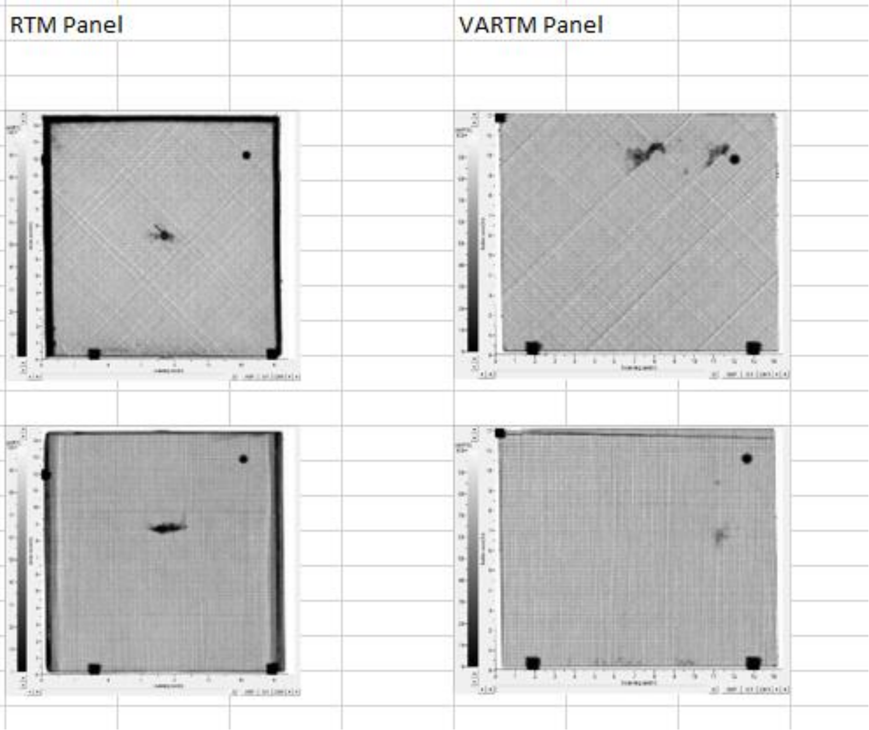
Laminate Table, All test at RTA					
Layup	**Approx Target Thickness (in)**	**# of NCF layers**	**D6484 Open Hole Compression**	**D5766 Open Hole Tension**	**D7136/D7137 CAI**
[45/-45/0/90]2s	0.116	8	5	5	5

Trial Phase

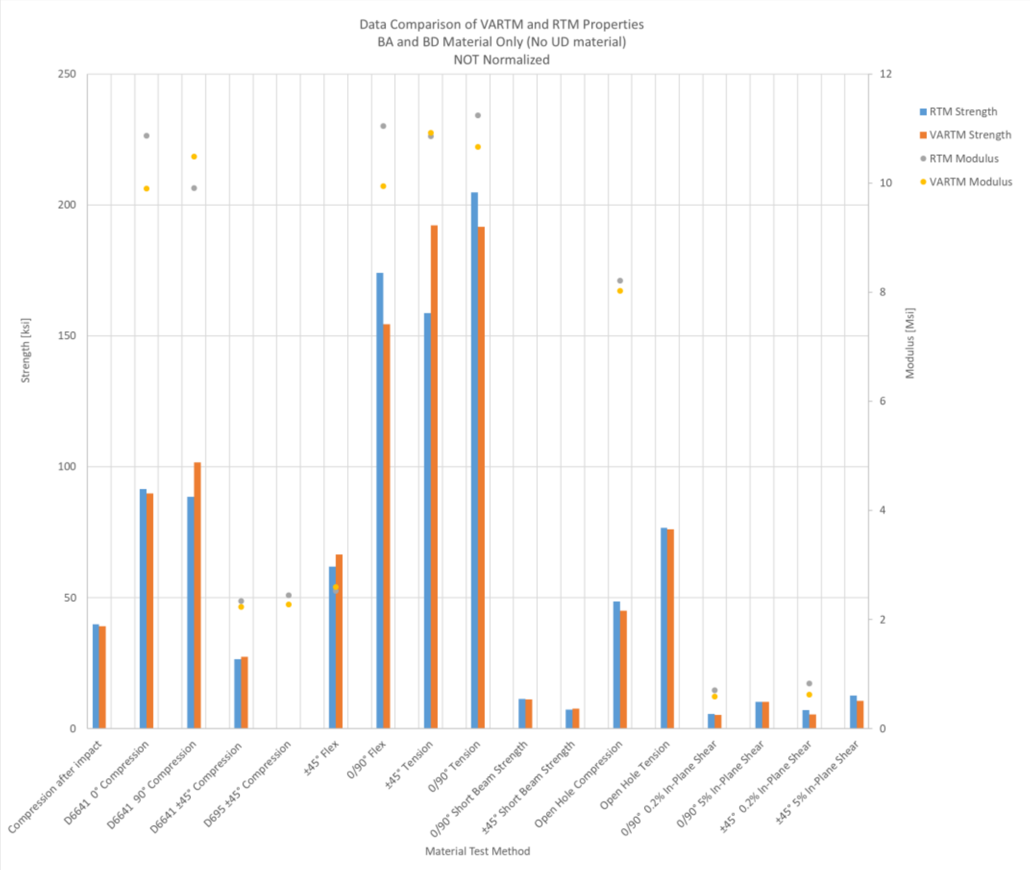
- 26 Panels
- Mechanical Properties, Physical properties
  - Tension, Compression, Flex, and Shear tests conducted
  - FV, RC, Voids, etc.
- General processing challenges
  - Identifying variables that need to be controlled
- NCF material properties
- Vacuum Assisted Resin transfer Molding vs Resin Transfer Molding (VARTM vs RTM)
  - Qual vs. Equiv; challenges, feasibility

Determining Processing Method





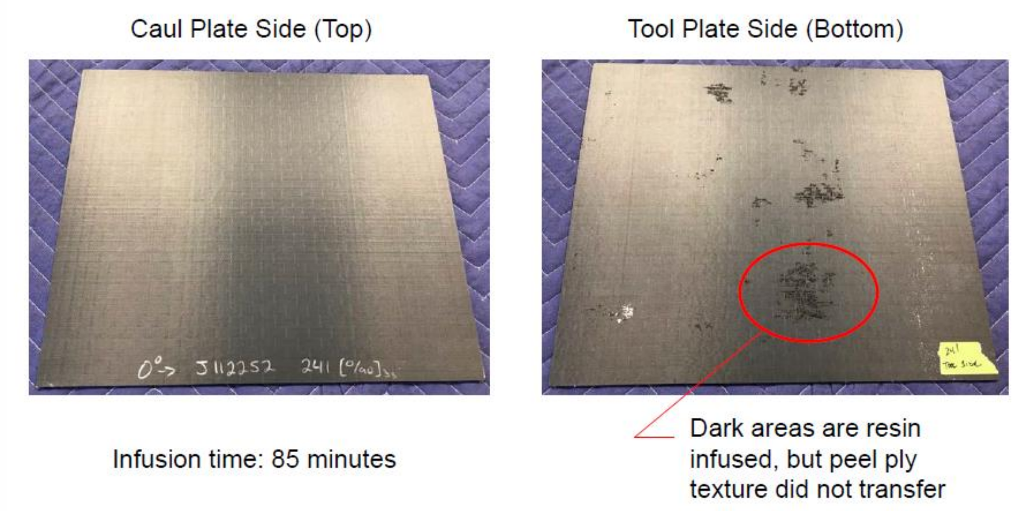
Determining Processing Method



- VARTM – more consistent, easier to work with
- Better panel quality
- Comparable results
- VARTM selected

Challenges

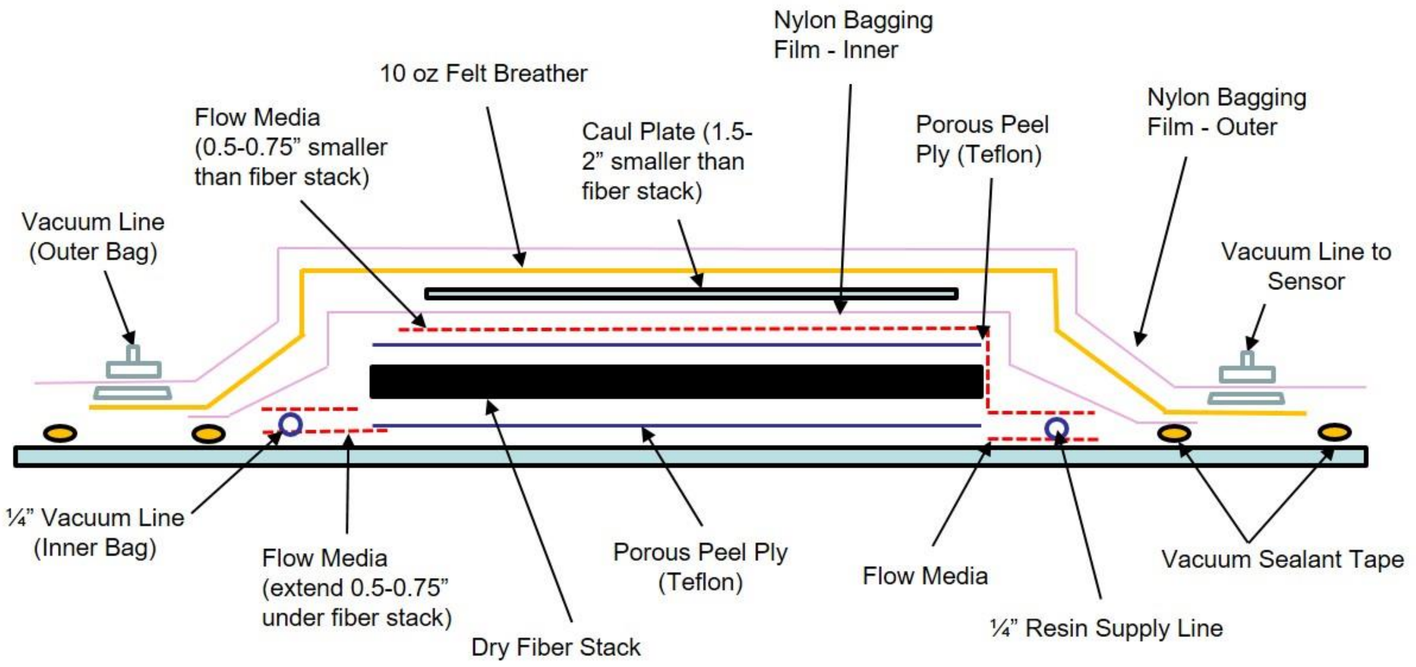
- Porosity, Improving Permeability
- Controlling fiber volume
- Initial weft density resulted in porosity and high infusion times.
- Varying weft density & changed flow media



Process Optimization

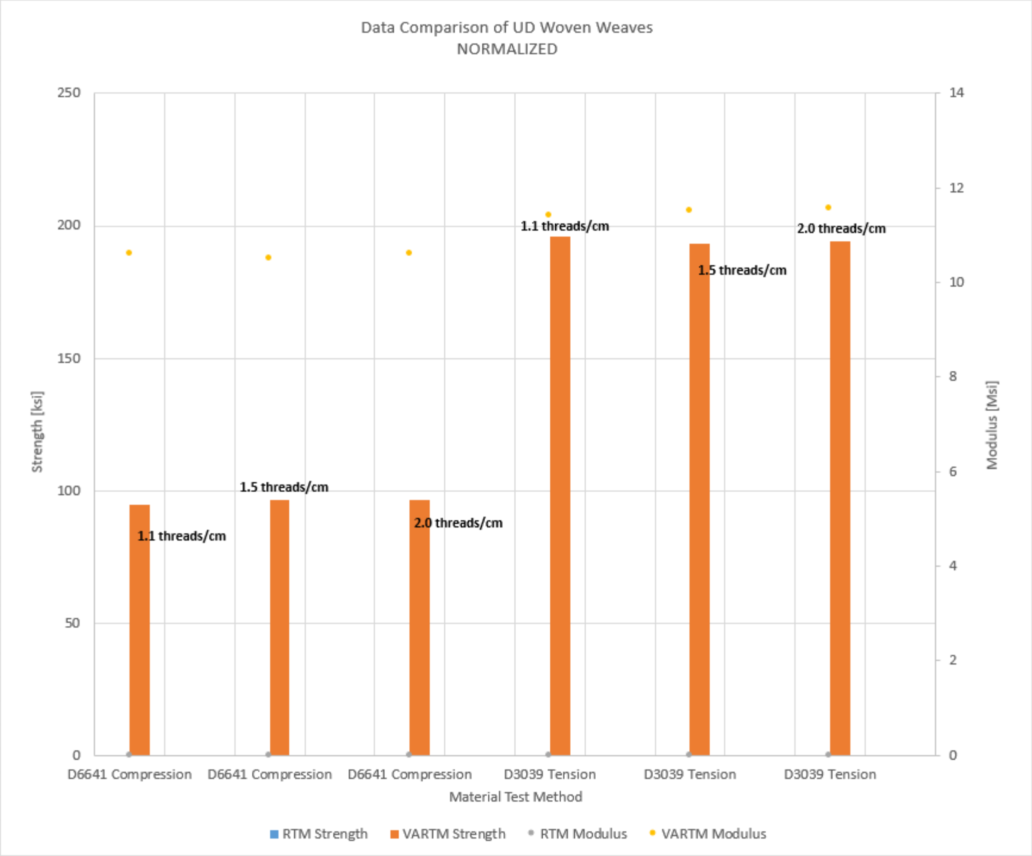
- NIAR and Teijin visited Fiber Dynamics
- Modification made to bagging scheme:
    - Varying flow media
    - Increased resin infusion temp.
    - Made port adjustments to improved infusion process
    - Adjusted tubing placement
    - Optimizing Infusion time and process
    - More repeatable FV
        - Target is 58% ± 2%
    - Weft density construction of UD material

Challenges – Bagging Scheme



Weft Density

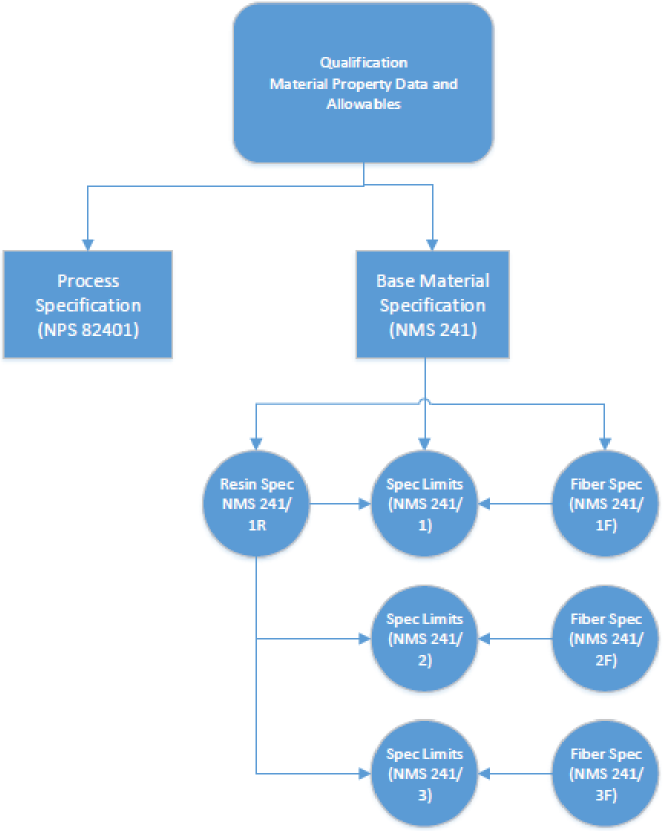
- Compared data and panel quality.
- Selected 1.5 threads/cm



Setting Qualification Framework

- Scope for Qual
  - Properties to generate from 5 products (two forms of BA, and BD and one form of UD)
  - Lamina and laminate (individual vs combined)
- Versatility
  - Future combinations of material to existing scope
  - Specification Structure

Specification Structure



Specification Series

NMS 241 Rev -
Date: June XX, 2021

Document No.: NMS 241 Revision -, June XX, 2021

NCAMP Material Specification
This specification is generated and maintained in accordance with NCAMP Standard Operating Procedures, NSP 100

Tenax® -E Dry Reinforcements

FOR TEST USE ONLY

Prepared by: Michelle Man (NCAMP), Royal Lovingfoss (NCAMP/NIAR)

Reviewed by: Rachael Andrulonis (NCAMP/NIAR), Vera Richter (Teijin Carbon), Joe Spangler (Teijin Carbon), Alfonso Lopez (Teijin Carbon), Gary Kidd (Solvay)

NPS 82400 Rev -
Date: July XX, 2021

Document No.: NPS 82400, Revision -, July XX, 2021

NCAMP Process Specification
This specification is generated and maintained in accordance with NCAMP Standard Operating Procedures, NSP 100

Fabrication of NMS 240 Qualification, Equivalency, and Acceptance Test Panels

Vacuum Assisted Resin Transfer Molding
Solvay PRISM™ EP2400 toughened epoxy resin

Prepared by: Royal Lovingfoss (NCAMP/NIAR), Michelle Man (NCAMP)

Reviewed by: Ric Abbott (NCAMP AER), Ed Hooper (NCAMP AER), Rachael Andrulonis (NCAMP/NIAR), Adam Arnold (Fiber Dynamics), Vera Richter (Teijin Carbon), Johannes Rehbein (Teijin Carbon), Joe Spangler (Teijin Carbon), Alfonso Lopez (Teijin Carbon), Gary Kidd (Solvay)

Distribution Statement A. Approved for public release; distribution is unlimited.

Specification Series

NIAR® Wichita State University
National Institute for Aviation Research
Composites & Advanced Materials

NIAR Wichita State University National Institute for Aviation Research

NMS 241/1R Rev -
Date: Aug XX , 2021

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NATIONAL CENTER for ADVANCED MATERIALS PERFORMANCE

Document No.: NMS 241/1R Revision -, August XX, 2021

NCAMP Material Procurement Specification
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FOR TEST USE ONLY

PRISM™ EP 2400 Toughened Epoxy Resin

Prepared by: Michelle Man (NCAMP), Royal Lovingfoss (NCAMP/NIAR), John Tomblin (NCAMP/NIAR)

Reviewed by: Rachael Andrulonis (NCAMP/NIAR), Ric Abbott (NCAMP AER), Ed Hooper (NCAMP AER), Gary Kidd (Solvay)

Distribution Statement A. Approved for public release; distribution is unlimited.

National Center for Advanced Materials Performance
Wichita State University – NIAR
1845 Fairmount Ave., Wichita, KS 67260-0093, USA

NIAR Wichita State University National Institute for Aviation Research

NMS 241/1F Rev -
Date: Aug XX , 2021

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Document No.: NMS 241/1F Revision -, August XX, 2021

NCAMP Material Procurement Specification
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FOR TEST USE ONLY

Tenax® -E Dry Reinforcements
Class 1, Style BA, Grade 380,

Prepared by: Michelle Man (NCAMP), Royal Lovingfoss (NCAMP/NIAR), John Tomblin (NCAMP/NIAR)

Reviewed by: Rachael Andrulonis (NCAMP/NIAR), Ric Abbott (NCAMP AER), Ed Hooper (NCAMP AER), Vera Richter (Teijin Carbon), Johannes Rehbein (Teijin Carbon), Joe Spangler (Teijin Carbon), Alfonso Lopez (Teijin Carbon),

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Test Plan

- Test plan – scope or lamina and laminate testing
    - Lamina properties for Biaxial, Bidiagonal and Unidirectional
    - Laminate properties for combination of materials
    - Quasi, Soft, Hard
    - 2nd hard layup (limited methods)
    - -65°F, RTD, 180°F, 250°F

Test Plan – Lamina (BA)

Fiber Layup	Test direction	Test Type	Property	Number of Batches x Number of Panels x Number of Test Specimens				
				Test Temperature/Moisture Condition				
				CTD (4)	RTD	ETW1	ETD	ETW2
$[0/90]_{4S}$	0°	ASTM D3039 Tension	Strength, Modulus, and Poisson's Ratio	3x2x3	3x2x3 (3)	1x2x3		3x2x3
$[0/90]_{4S}$	0°	ASTM D6641 Compression	Strength and Modulus		3x2x3 (1)	1x2x3	1x2x3	3x2x3
$[0/90]_{4S}$	90°	ASTM D3039 Tension	Strength and Modulus	3x2x3	3x2x3 (3)	1x2x3		3x2x3
$[0/90]_{4S}$	90°	ASTM D6641 Compression	Strength and Modulus		3x2x3 (1)	1x2x3	1x2x3	3x2x3
$[45/-45]_{3S}$ (rotated out of 0/90 and 90/0)	0°	ASTM D3518 In-Plane Shear (2)	Strength and Modulus	3x2x3	3x2x3 (3)	1x2x3		3x2x3
$[0/90]_{8S}$	0°	ASTM D2344 Short Beam	Strength	3x2x3	3x2x3	1x2x3	1x2x3	3x2x3

Test Plan – Lamina (UD)

Fiber Layup	Test direction	Test Type	Property	Number of Batches x Number of Panels x Number of Test Specimens Test Temperature/Moisture Condition				
				CTD (4)	RTD	ETW1	ETD	ETW2
$[0/90]_{4S}$	0°	ASTM D3039 Tension	Strength, Modulus, and Poisson's Ratio	3x2x3	3x2x3 (3)	1x2x3		3x2x3
$[0/90]_{4S}$	0°	ASTM D6641 Compression	Strength and Modulus		3x2x3 (1)	1x2x3	1x2x3	3x2x3
$[0]_8$	0°	ASTM D3039 Tension	Strength and Modulus	3x2x3	3x2x3 (3)	1x2x3	1x2x3	3x2x3
$[0]_8$	0°	ASTM D6641 Compression	Modulus		3x2x3 (1)	1x2x3	1x2x3	3x2x3
$[45/-45]_{3S}$	0°	ASTM D3518 In-Plane Shear (2)	Strength and Modulus	3x2x3	3x2x3	1x2x3		3x2x3
[0]32	0°	ASTM D2344 Short Beam	Strength	3x2x3	3x2x3	1x2x3	1x2x3	3x2x3

Test Plan – Laminate

- Laminate properties for combination of materials
- Quasi (25/50/25) – BA and BD
  - [(45/-45), (0/90), (45/-45), (90/0) | (0/90), (-45/45), (90/0), (-45/45)]
- Soft (12.5/75/12.5) – BD and UD
  - [(45/-45), (0/90), (45/-45), (45/-45) | (-45/45), (-45/45), (90/0) (-45/45)]
- Hard (50/40/10) – BA, BD and UD
  - [(45/-45), 0, 0, (0/90), (45/-45) , 0, 0 | 0, 0, (-45/45), (90/0), 0, 0, (-45/45)]
- 2nd hard layup - (37.5/25/37.5)
  - [(90/0), (45/-45), (0/90), (0/90) | (90/0), (90/0), (-45/45), (0/90)]

Anticipated Challenges

- FV range - porosity and permeability
  - During trial porosity observable in center; upsizing fabrication size may lead to increased porosity.
- Variation in fabrication – thickness, size, material combinations
- Proper control of Key Process Variables – identifying and establishing controls for them.
- Unknowns to pop up

Future Work

- Next steps and planned work
    - Complete Test Plan and Specification Series
    - Quantify material needs
    - Begin Qualification efforts
- Ensure suitability of exiting statistical methods for data analysis

Technical Publications

- Annual report on Research Accomplishments to the FAA, Dec 2020
- Annual report on Research Accomplishments to the FAA, Dec 2021
- Data and report to be published on NCAMP website
- Data submission to CMH17
- Permeability document – collaboration with Teijin and other partners

THANK YOU

Questions?