Resin Infused Fiber Reinforced Materials Guidelines for Aircraft Design and Certification Process
»April 2023 UPDATE

Presented by:

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April 19, 2023

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:** Dave Stanley
- **FAA Sponsors:** Cindy Ashforth, Larry Ilcewicz
- **Industry Partnerships/Other Collaborations**
  - Solvay, Teijin, Fiber Dynamics, several other industry committee members

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 using the NCAMP process.
- Secondary goal: To transition the test data and guidelines generated in this program into shared databases, such as CMH-17.

Current Status

2020	2021-2022	2022-2023	2023	2023-2024
Survey & Establish Steering Committee	Develop Qualification Framework	Validate framework with selected materials	Establish statistical guidelines	Transition - Material property data - Guidelines

Technical Approach Overview

- ✓ Survey OEM designers, manufacturers/user and experts on material selection
- ✓ Committee Review Group established – Industry users, suppliers, FAA
- ✓ Material selection narrowed
  - ✓ Resin: Solvay PRISM™ EP 2400
  - ✓ Reinforcement: Tenax™-E IMS65 Non-Crimp Reinforcement (Stitched); UD Fabric, Bi-axial (0/90), and Bi-diagonal (+/-45)
- ✓ Processing Method – VARTM
- ✓ 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
- **Qualification test data sufficient for developing statistical guidelines and allowables**
- **Data and Guidelines**

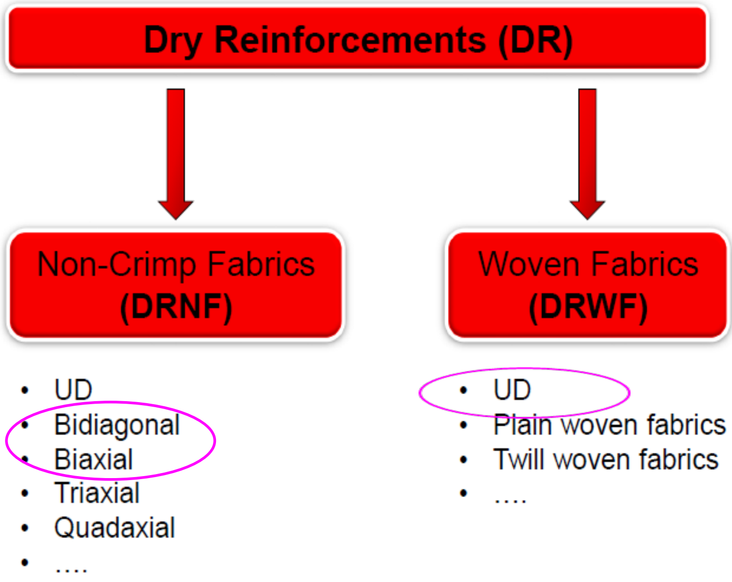
Milestones & Timeline

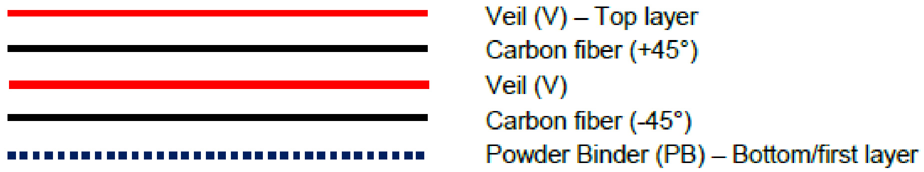
Done Jan 2023	Documentation	Test Plan	Process Specification	Laminate Material Specification	Fabric Material Specification	Resin Material Specification
Feb - Aug 2023	Panel Production	Batch A	Batch B	Batch C		
Feb – mid Aug 2023	Specimen Prep	Machining & Conformity	Specimen to Chamber	Testing (~Aug 2023)		
Mid Aug – Oct 2023	Testing	Ambient	Fluid Screening	Moisture Equilibrium	Data Availability	
Q1 2024	Data Review	Concerns? •Retests?	Summary Sheets			
Q2 2024	Documentation	Data Report Draft	Statistics Report Draft	NMS/NPS updates	FAA Guidance Doc	

I'm done!
Active/Ongoing
Next task

Material Forms

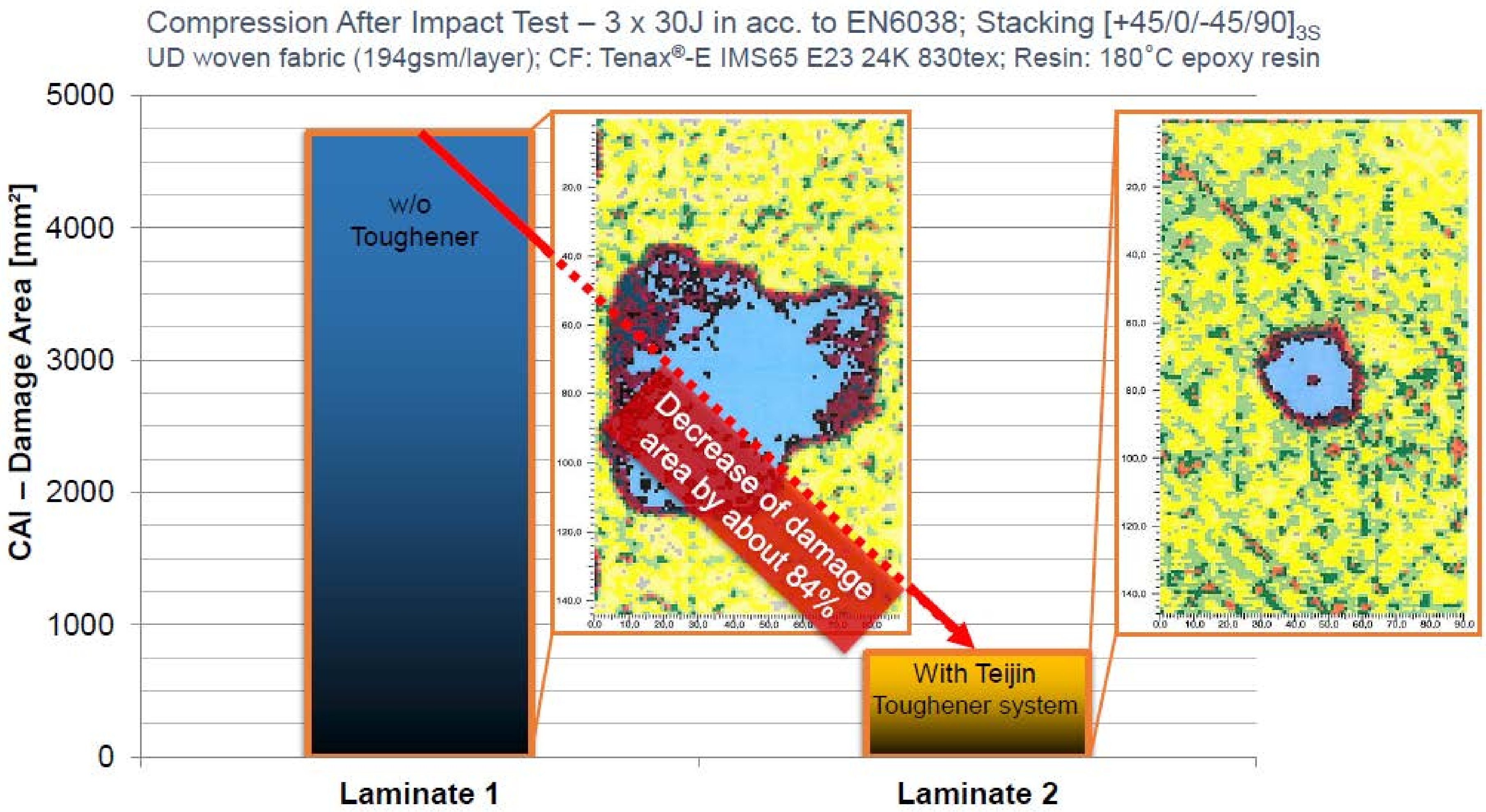
- **Reinforcement**: Tenax™-E IMS65 Non-Crimp Reinforcement
- **Material Forms**:
  - Biaxial (BA) – carbon fibers in 0°/90° or 90°/0°
  - Bidiagonal (BD) – carbon fibers in +45°/-45° or -45°/+45° (also in ±30° and ±60°)
  - UD (woven with yarn)
- **Toughening veil:** TA1903s (polyamide veil) used to improve material toughness.
- **Powder binder**: Hexion EP05311 binder resin improves material cutting and handling and aids in preforming and tacking two layers of textile together.
- **Stitching Yarns**:
  - NCF: K-203 (EP1390) 33 dtex a co-polyamide yarn
  - UD Woven: polyester and co-polyamide Z-85 combi-fuseable bonding yarn, 200 dtex.
- **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



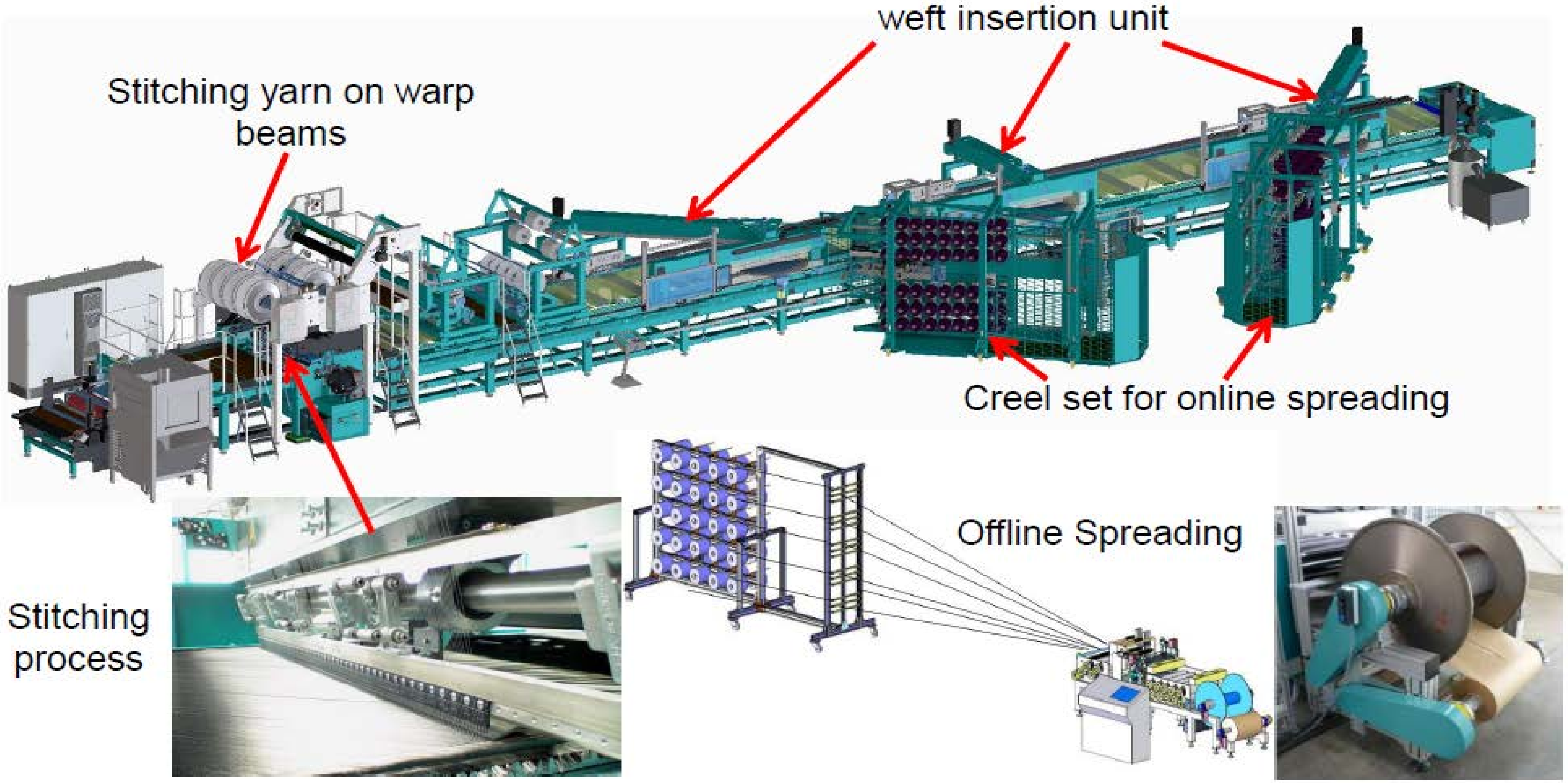


Detail Construction of Bidiagonal NCF

Effect of Veil



Teijin NCF Manufacturing Facility

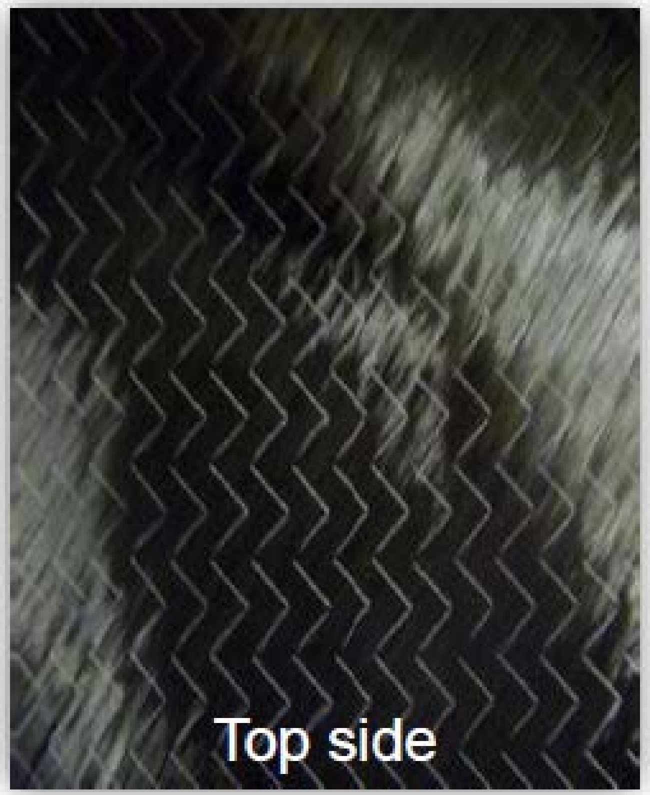


Reinforcement – Stitching Techniques

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

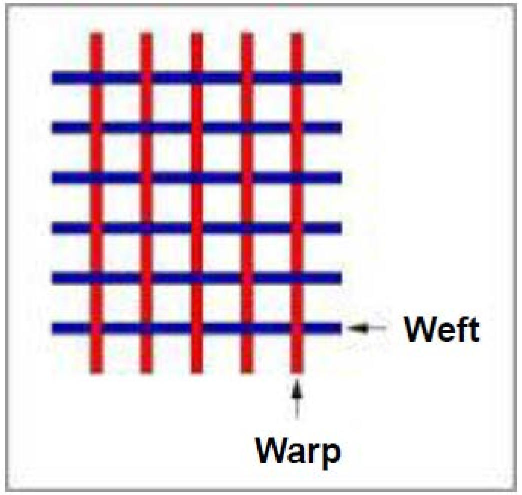
Reinforcement – Stitching Techniques

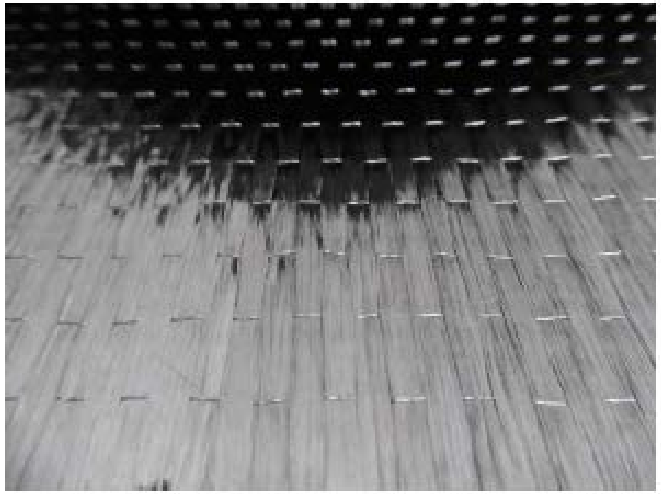
- Tricot Stitch
  - Best drapeability
  - Additional improvements possible – stitching length and loop stitch
  - Used in Biaxial NCF (tricot loop)

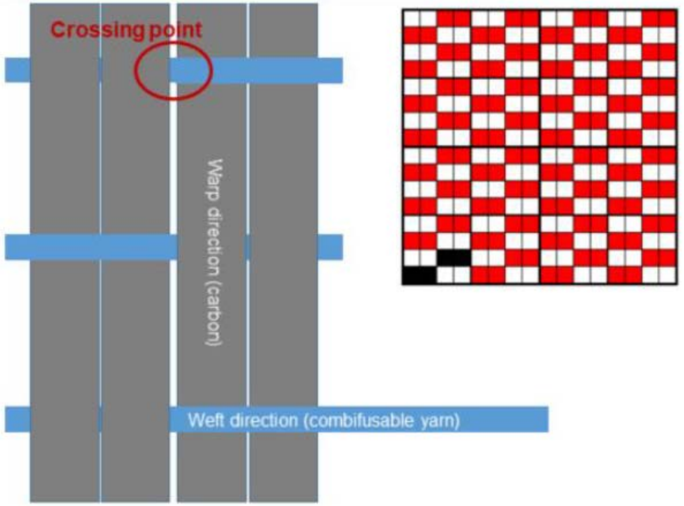


Reinforcement – UD (woven)

- UD Woven
  - Warp – Carbon fibers
  - Weft – Combi-fuseable yarn woven into the fibers
  - Provide localized reinforcement
  - Veil and Fiber
  - Increasing crossing point improves permeability
  - Balance between crossing point and mechanical performance







Trial Phase

- **Panel fabrication**
  - 26 Panels fabricated at Fiber Dynamics
- **Properties evaluated**
  - Mechanical: Tension, Compression, Flex, and Shear tests conducted
  - Physical: Fiber volumes, resin contents, voids, etc.
- **General processing challenges**
  - Identifying variables that need to be controlled
- **Manufacturing process differences**
  - Vacuum Assisted Resin transfer Molding vs Resin Transfer Molding (VARTM vs RTM)
  - Qualification vs. equivalency; challenges, feasibility

Trial Phase

Lamina Table, All test at RTA

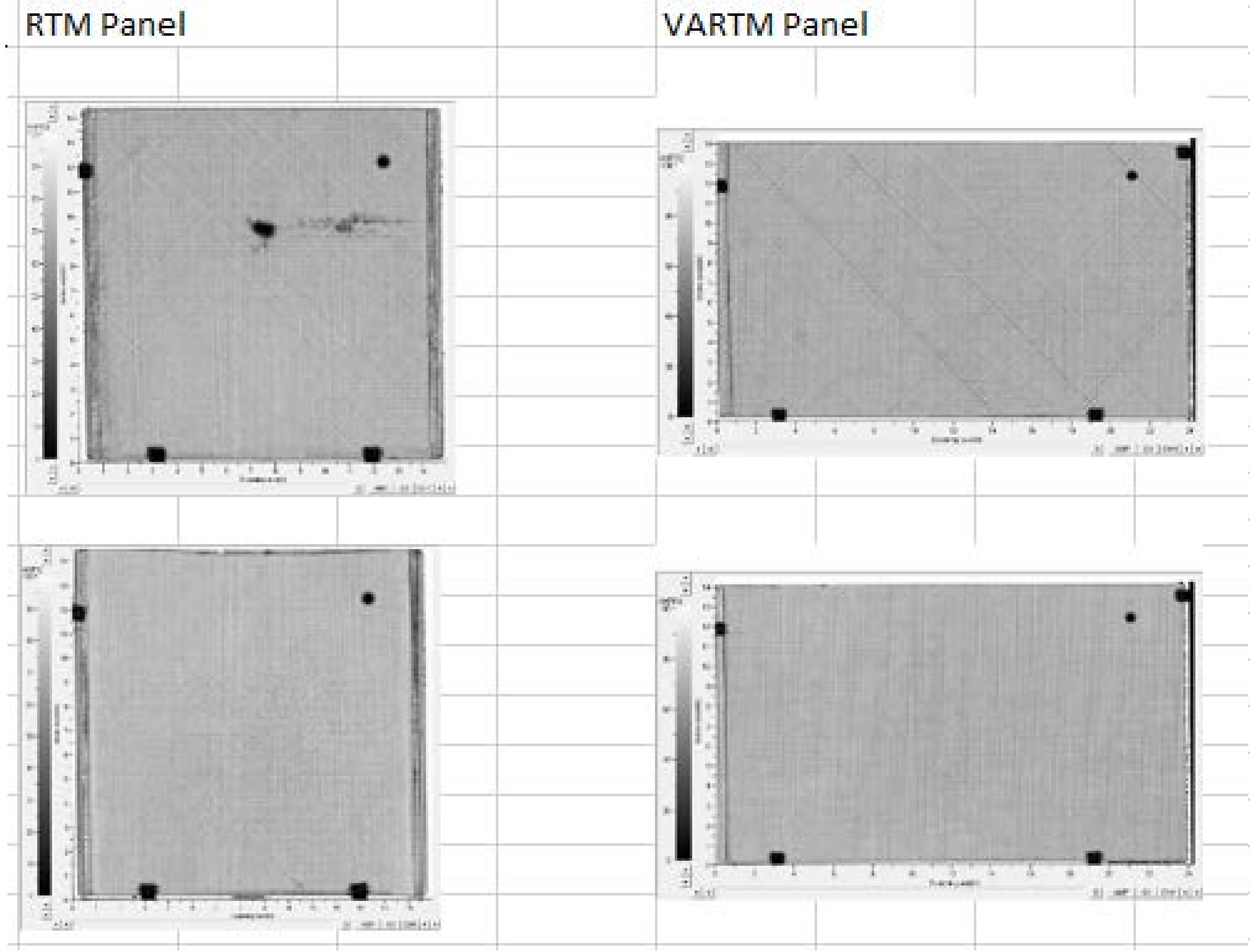
Layup	Approx Target Thickness (in)	# of NCF layers	D3039 Tension	D6641	D3518 In-Plane Shear	D2344 Short Beam Shear	D790 Flex
[45/-45]3s	0.087 - 0.090	6	5 (rotated panel)	5*	5		5
[0/90]3s	0.087 - 0.090	6	5	5 in 0 and 5 in 90	5 (rotated panel)		5
[45/-45]6s	0.174 - 0.180	12				5	
[0/90]6s	0.174 - 0.180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

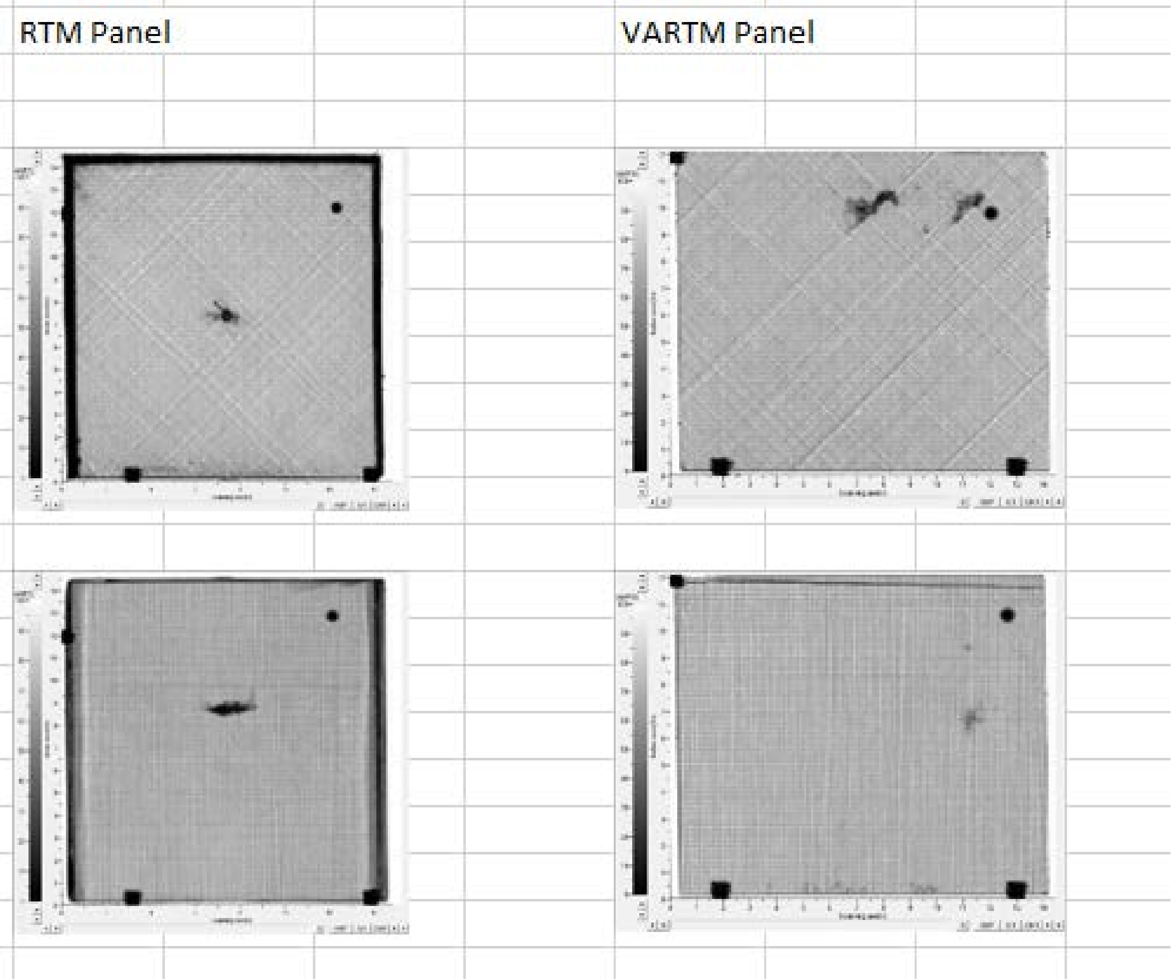
* additional 5 for Dogbone D695 geometry

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

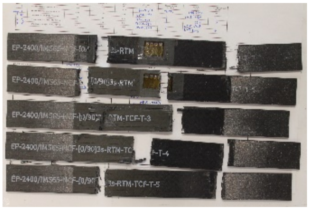
Determining Processing Method



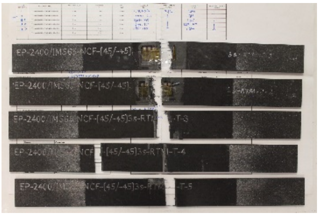


Determining Processing Method

- ✓ VARTM – more consistent, easier to work with, better process control
- ✓ Better panel quality
- ✓ Comparable results to RTM
- ✓ VARTM selected



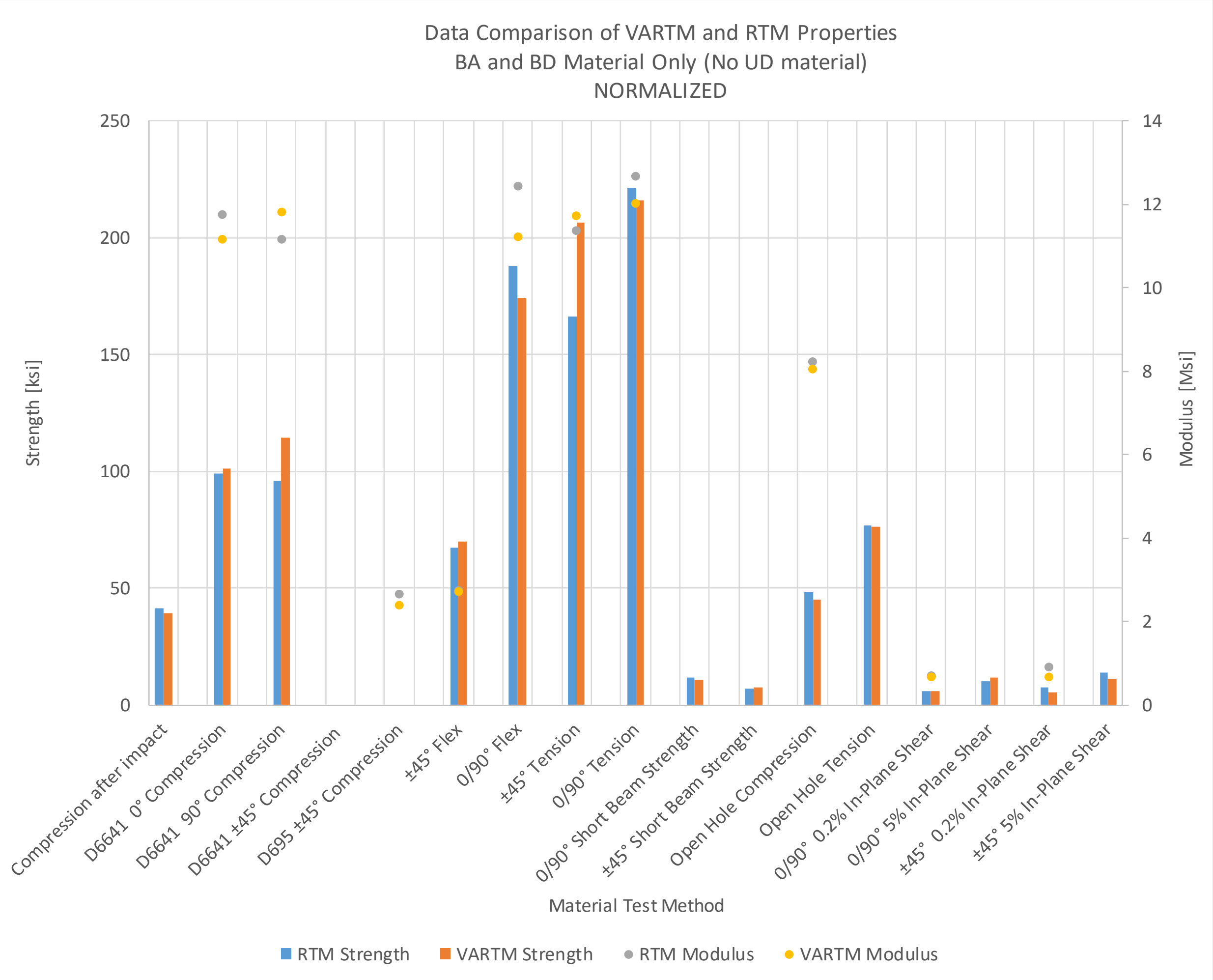
RTM, [0/90]



RTM, [45/-45]

VARTM, [0/90]

Tension Specimens Post-Test for RTM and VARTM



Processing Challenges

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

Caul Plate Side (Top)

Tool Plate Side (Bottom)

Infusion time: 85 minutes

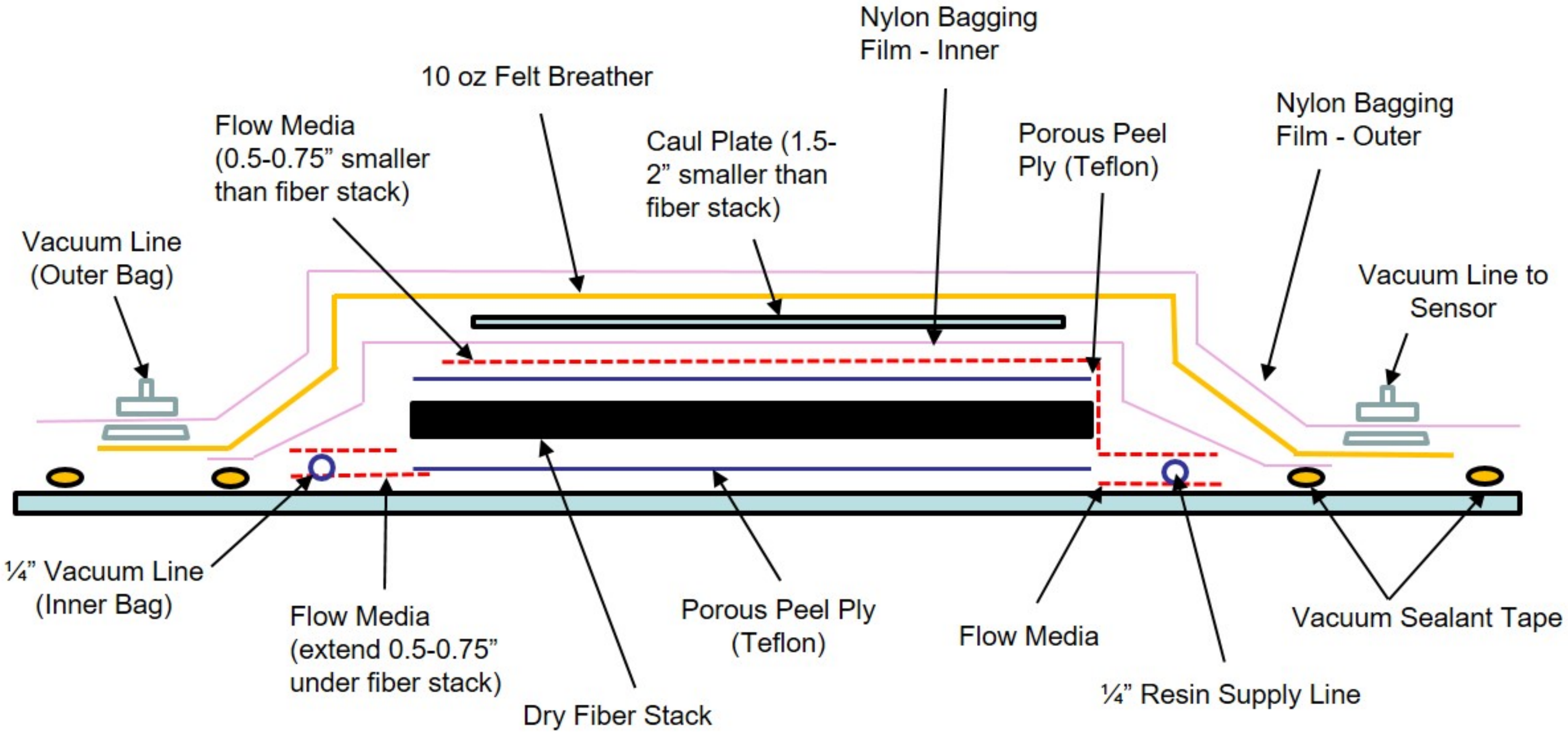
Dark areas are resin infused, but peel ply texture did not transfer

VARTM Uni-Fabric Panel

Courtesy of Fiber Dynamics, Inc.

Process Optimization

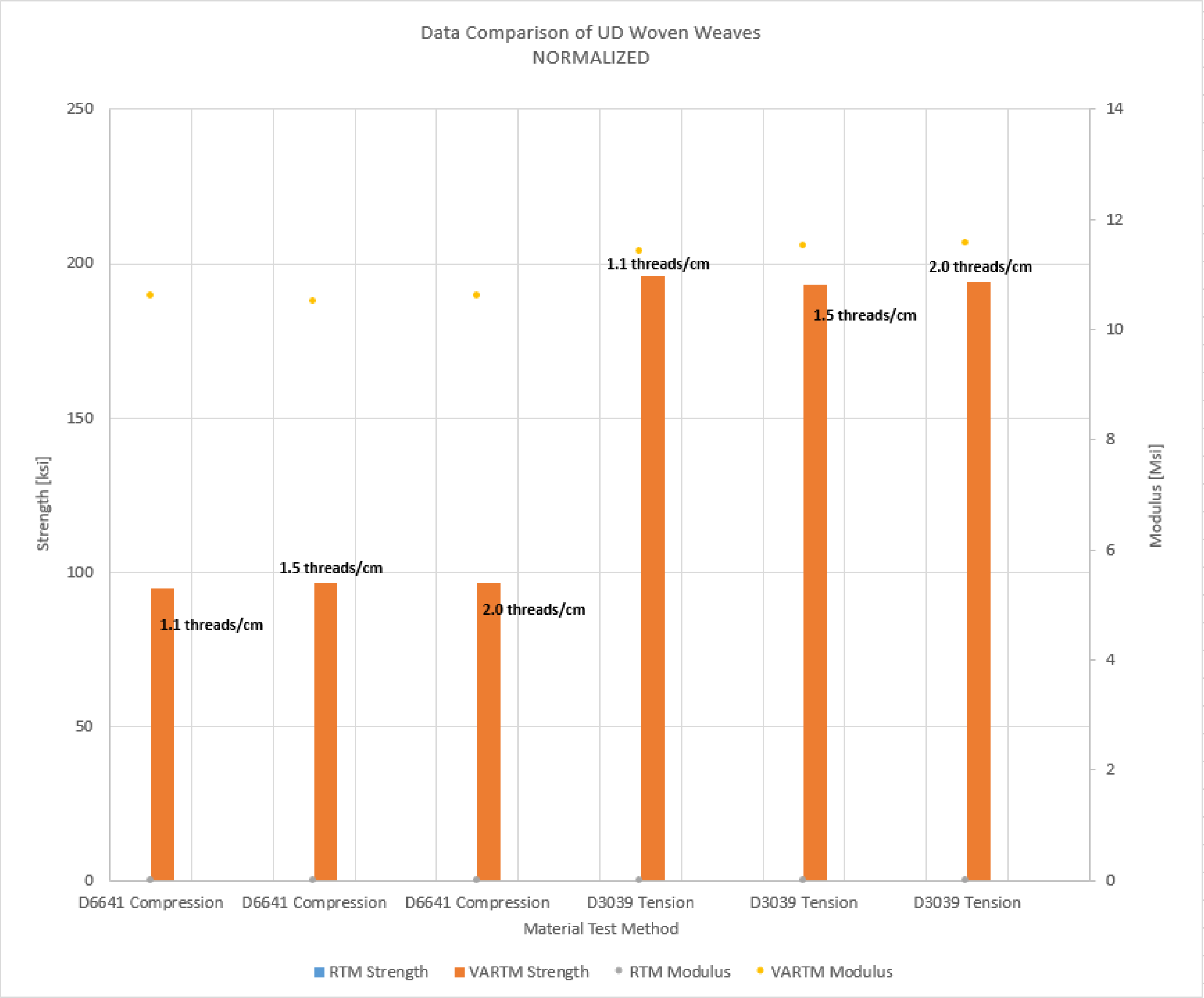
- NIAR and Teijin visited Fiber Dynamics
- Modification made to bagging scheme:
  - Varying flow media
  - Increased resin infusion temp.
  - Made port adjustments to improved infusion process
  - Adjusted tubing placement
  - Optimizing Infusion time and process
  - More repeatable FV
    - Target is 57% ± 3%
  - Weft density construction of UD material



Weft Density

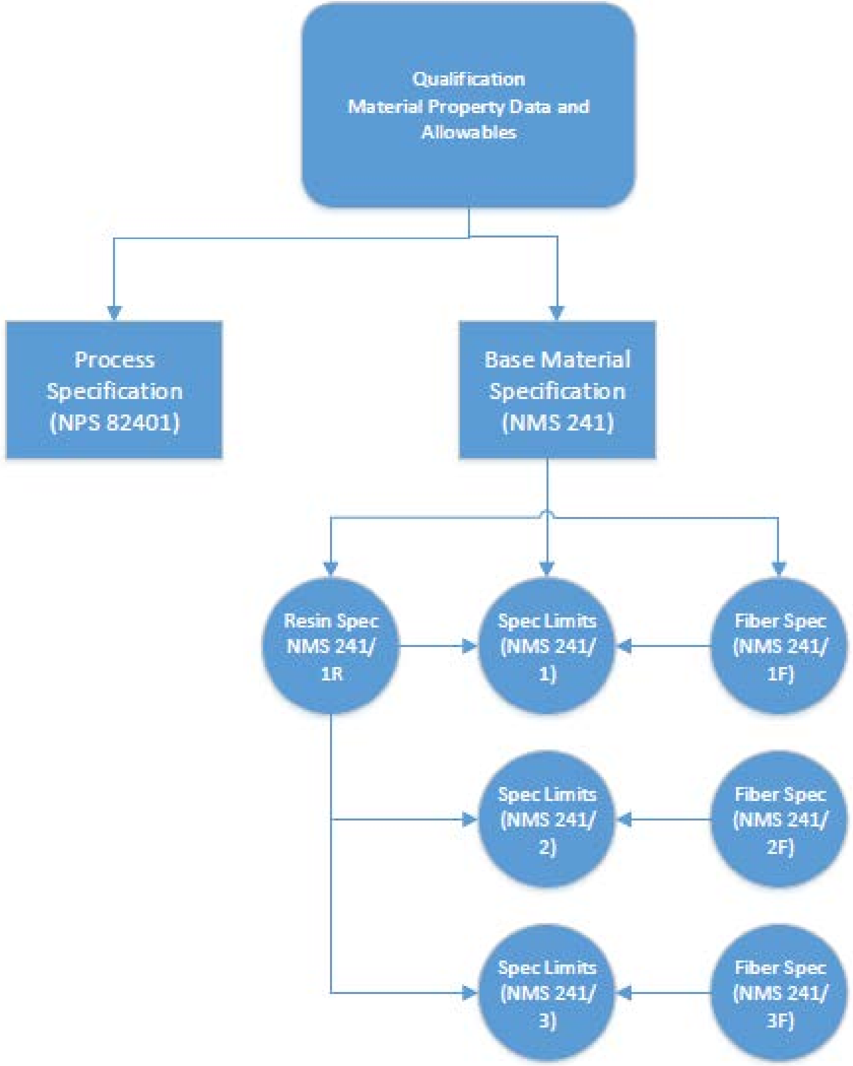
Compared data and panel quality.

Selected 1.5 threads/cm



Setting the Qualification Framework

- **Specifications are organized for versatility and future use/expansion**
- Properties will be generated from 5 products:
  - Two forms of BA
  - Two forms of BD
  - One form of UD
- Lamina and laminate properties
  - Individual form
  - Combined forms



Specification Series

- **NMS 241F** – Base Fabric Specification (defines requirements for the dry reinforcements)
  - NMS 241F/1 – Biaxial DRNF
  - NMS 241F/2 – Bidiagonal DRNF
  - NMS 241F/3 – UD Woven DRWF
- **NMS 241R** – Base Resin Specification (defines requirements for the resin)
  - NMS 241R/1 – EP2400
- **NMS 241** – Base Laminate Specification (defines requirement for the finished laminates)
  - NMS 241/1 – Biaxial Laminates
  - NMS 241/2 – Bidiagonal Laminates
  - NMS 241/3 – UD Woven Laminates
- **NPS 82401** - Process specification describes the methods of fabricating test panels using a vacuum assisted resin transfer molding process with PRISM™ EP2400 Resin System.

Test Plan

- **Test plan – lamina and laminate testing**
  - Lamina properties for Biaxial, Bidiagonal and Unidirectional
  - Laminate properties for combination of materials
  - Quasi, Soft, Hard
  - -65°F, RTD, 180°F, 250°F

NIAR | Wichita State University | National Institute for Aviation Research

NTP 2401Q1 Rev -

NCAMP — NATIONAL CENTER for ADVANCED MATERIALS PERFORMANCE

Fiber Supplier Contact:	Resin Supplier Contact:	Panel Fabricator Contact:
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NCAMP Project Number NPN 072101

Document No.: NTP 2401Q1 Rev -

Material Property Data Acquisition and Qualification Test Plan For

Vacuum Assisted Resin Transfer Molding

Resin System: Solvay PRISM™ EP2400 toughened epoxy resin

Dry Reinforcement: Tenax™ - E Reinforcement Fabrics

Prepared by: Michelle Man (NCAMP)

Reviewed by: Ed Hooper (NCAMP AER), Rachael Andrulonis (NIAR), Royal Lovingfoss (NIAR), Adam Arnold (Fiber Dynamics), Joe Spangler (Teijin Carbon), Alfonso Lopez (Teijin Carbon), Elisabeth Schäfer (Teijin Carbon), Patrick Kistner (Teijin Carbon), Martin Linder (Teijin Carbon), Gary Kidd (Solvay)

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

Test Plan – Lamina (BA, BD, UD)

Fiber Layup	Test direction	Test Type	Property	Number of Batches x Number of Panels x Number of Test Specimens Test Temperature/Moisture Condition				
				CTA (4)	RTA	ETA	ETW1	ETW2
[0/90]$_{4S}$	0°	ASTM D3039 Tension	Strength, Modulus, and Poisson's Ratio	3x2x3	3x2x3 (3)	3x2x3	3x2x3	
[0/90]$_{4S}$	0°	ASTM D6641 Compression	Strength and Modulus		3x2x3 (1)	3x2x3	3x2x3	1x2x3
[0/90]$_{4S}$	90°	ASTM D3039 Tension	Strength and Modulus	3x2x3	3x2x3 (3)	3x2x3	3x2x3	
[0/90]$_{4S}$	90°	ASTM D6641 Compression	Strength and Modulus		3x2x3 (1)	3x2x3	3x2x3	1x2x3
[45/-45]$_{3S}$ (rotated out of 0/90 and 90/0)	0°	ASTM D3518 In-Plane Shear (2)	Strength and Modulus	3x2x3	3x2x3 (3)	3x2x3	3x2x3	
[0/90]$_{8S}$	0°	ASTM D2344 Short Beam	Strength	3x2x3	3x2x3	3x2x3	3x2x3	1x2x3
[0/90]$_{4S}$	0°	ASTM D7264 Flex (5)	Strength and Modulus		3x2x3			

Biaxial Lamina Mechanical Test Matrix

Fiber Layup	Test direction	Test Type	Property	Number of Batches x Number of Panels x Number of Test Specimens Test Temperature/Moisture Condition				
				CTA (4)	RTA	ETA	ETW1	ETW2
[0/90]$_{4S}$ (BD rotated by 45°)	0°	ASTM D3039 Tension	Strength, Modulus, and Poisson's Ratio	3x2x3	3x2x3 (3)	3x2x3	3x2x3	
[0/90]$_{4S}$ (BD rotated by 45°)	0°	ASTM D6641 Compression	Strength and Modulus		3x2x3 (1)	3x2x3	3x2x3	1x2x3
[45/-45]$_{3S}$	0°	ASTM D3518 In-Plane Shear (2)	Strength and Modulus	3x2x3	3x2x3 (3)	3x2x3	3x2x3	
[0/90]$_{8S}$ (BD rotated by 45°)	0°	ASTM D2344 Short Beam	Strength	3x2x3	3x2x3	3x2x3	3x2x3	1x2x3
[0/90]$_{4S}$ (BD rotated by 45°)	0°	ASTM D7264 Flex (5)	Strength and Modulus		3x2x3			

Bidiagonal Lamina Mechanical Test Matrix

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: CTA (4)	RTA	ETA	ETW1	ETW2
$[0/90]_{4S}$	0°	ASTM D3039 Tension	Strength, Modulus, and Poisson's Ratio	3x2x3	3x2x3 (3)	3x2x3	3x2x3	
$[0/90]_{4S}$	0°	ASTM D6641 Compression	Strength and Modulus		3x2x3 (1)	3x2x3	3x2x3	1x2x3
$[0]_8$	0°	ASTM D3039 Tabbed Tension	Strength and Modulus	3x2x3	3x2x3 (3)	3x2x3	3x2x3	1x2x3
$[0]_{16}$	0°	ASTM D6641 Compression	Modulus		3x2x3 (1)	3x2x3	3x2x3	1x2x3
$[45/-45]_{3S}$	0°	ASTM D3518 In-Plane Shear (2)	Strength and Modulus	3x2x3	3x2x3	3x2x3	3x2x3	
[0]32	0°	ASTM D2344 Short Beam	Strength	3x2x3	3x2x3	3x2x3	3x2x3	1x2x3
$[0/90]_{4S}$	0°	ASTM D7264 Flex (5)	Strength and Modulus		3x2x3			

UD Woven Lamina Mechanical Test Matrix

Laminate Mechanical Properties

- The construction of the laminates are done using a combination of the non-crimp and woven fabric forms to produce the desired quasi, soft, and hard orientation.
- The layup angles 0/90, 90/0, 45/-45 and -45/45 refer to the specific DRNF, i.e. biaxial (0/90 or 90/0) and bidiagonal (45/-45 or -45/45) reinforcement fabric.
- The stacking sequences were chosen based on several factors:
  - to assess the scope of material properties from a soft, quasi and hard construction
  - to assess the interactions of the different preforms
  - to assess the process ability of the different preforms when used jointly.

Properties include:

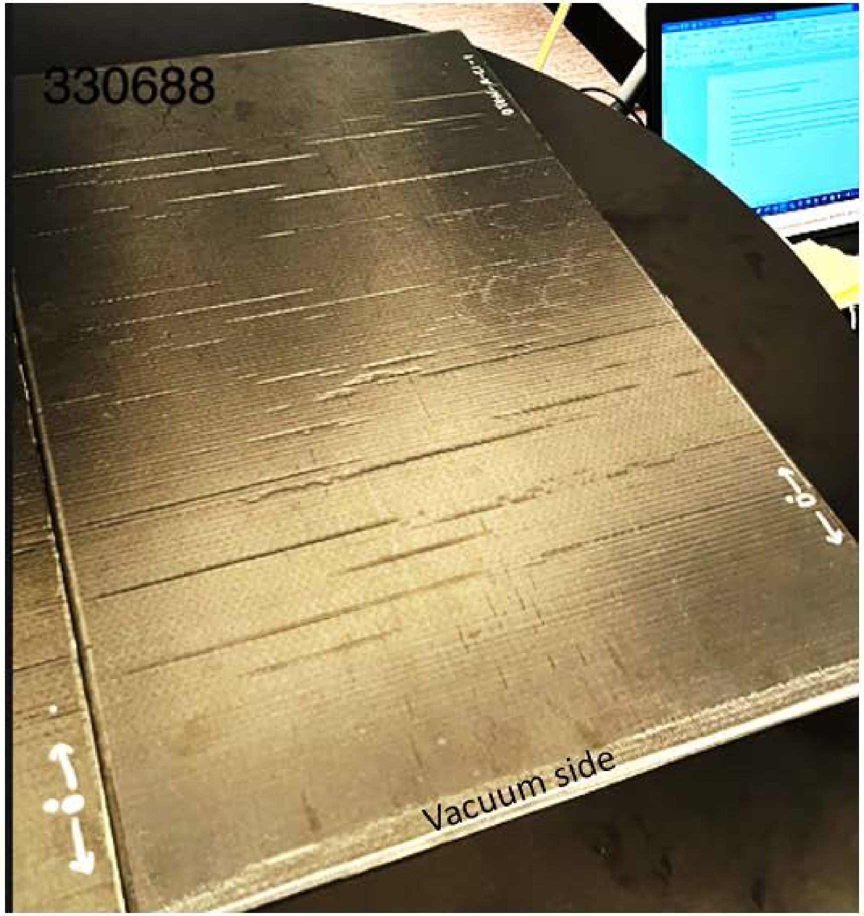
- Unnotched Tension
- Unnotched Compression
- Short Beam Shear
- Open Hole Tension
- Filled Hole Tension
- Open Hole Compression
- Filled Hole Compression
- Single Shear Bearing
- Interlaminar Tension
- Compression After Impact

Fluid Screening:

- Woven Fabric
- Short Beam Shear
- 13 fluids + controls
- RT and ET testing

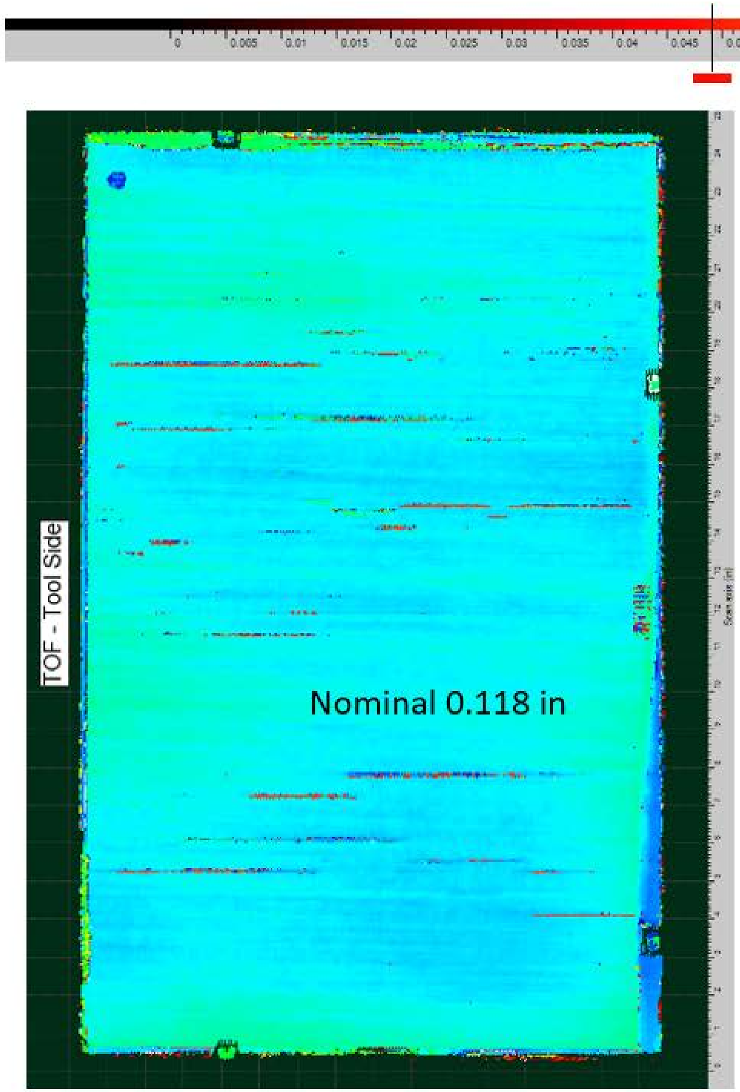
Lessons to Learn

Surface picture of Panel A-C2-2 number 330688

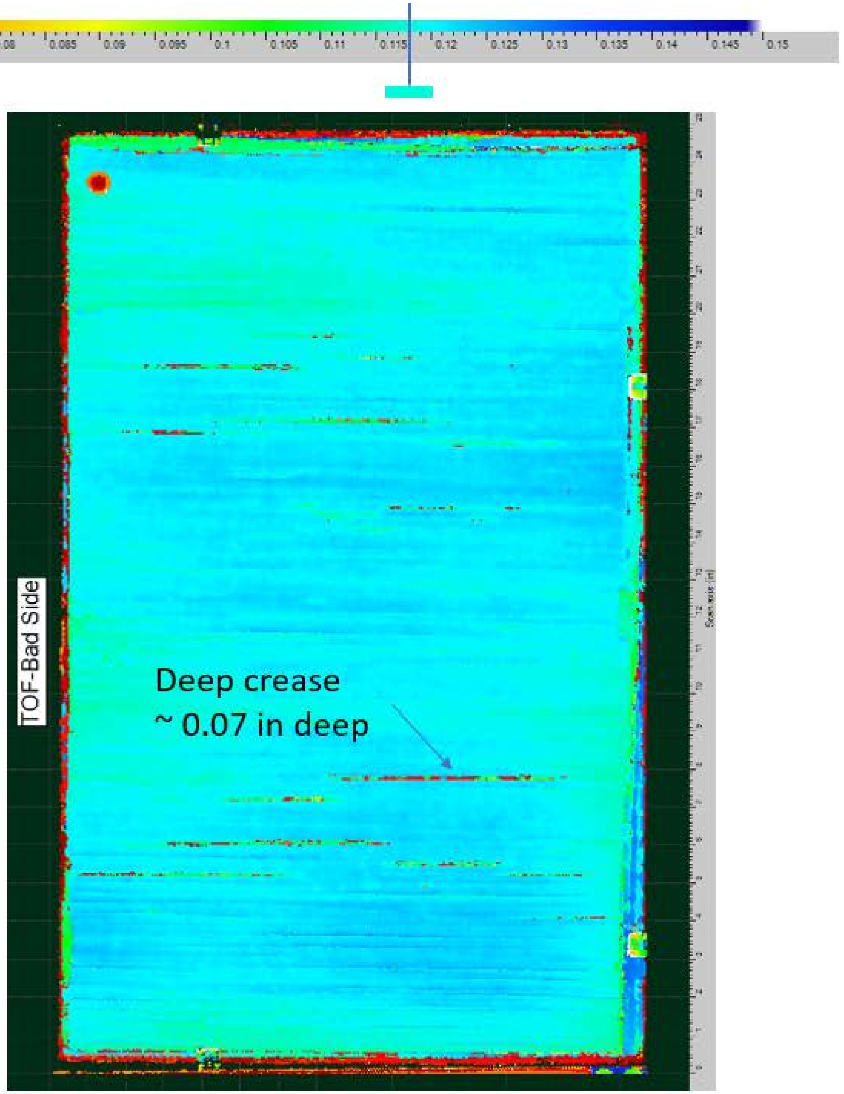


Most severe creases of all panels

Lessons to Learn



Zero tension
Panel A-C2-2
number 330688



Ongoing Activity

Qualification Documents

- Approved by project AER and released

Qualification Panels

- Raw materials (resin and fiber) received mid/late 2022
- Panel production began Dec 2022
- Batch A in progress
  - Batch B and C to follow
- 44 panels received
  - 28 scanned/machined

Challenges

- Processing
  - Vacuum leak rates
- Surface porosity/dry
  - Adjustments to bagging media
- Wrinkling
  - Teijin worked with Fiber Dynamics for resolution
  - Efforts ongoing
  - 4 panels affected
  - Lessons Learned Report
    - Processing
    - Material Property data effects

Publications

- FAA Annual Reports submitted: 2020, 2021
- Upcoming Tech Report submission: ECD May 31, 2023
  - Detail pre-qualification trials
  - Reference qualification
- Planned Reports:
  - Qualification Reports – NCAMP, FAA
  - Specifications - NCAMP
  - Material Specification Guidelines – FAA
  - Lessons Learned Report – NCAMP, FAA