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

Presented by:

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NIAR at Wichita State University

JAMS Technical Review
September 29th, 2021
Introduction

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

• Project Participants
  • Dr. John Tomblin, Rachael Andruilonis, 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

Veil (V)  
Carbon fiber  
Veil (V)  
Carbon fiber  
Powder Binder (PB)
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

Compression After Impact Test – 3 x 30J in acc. to EN6038; Stacking [+45/0/-45/90]_3s
UD woven fabric (194gsm/layer); CF: Tenax®-E IMS65 E23 24K 830tex; Resin: 180°C epoxy resin

- Laminate 1: w/o Toughener
- Laminate 2: With Teijin Toughener system

Decrease of damage area by about 84%
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

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

### Laminate Table, All test at RTA

<table>
<thead>
<tr>
<th>Layup</th>
<th>Approx Target Thickness (in)</th>
<th># of NCF layers</th>
<th>D6484 Open Hole Compression</th>
<th>D5766 Open Hole Tension</th>
<th>D7136/D7137 CAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>[45/-45/0/90]2s</td>
<td>0.116</td>
<td>8</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>
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

Infusion time: 85 minutes

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

- 10 oz Felt Breather
- Nylon Bagging Film - Inner
- Nylon Bagging Film - Outer
- Caul Plate (1.5-2" smaller than fiber stack)
- Porous Peel Ply (Teflon)
- Vacuum Line to Sensor
- Vacuum Sealant Tape
- Dry Fiber Stack
- Flow Media (0.5-0.75" smaller than fiber stack)
- Flow Media (extend 0.5-0.75" under fiber stack)
- ⅛" Vacuum Line (Inner Bag)
- ¼" Vacuum Line (Outer Bag)
- ¼" Resin Supply Line
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

Qualification
Material Property Data and Allowables

Process
Specification
(NPS 02401)

Base Material
Specification
(NMS 241)

Resin Spec
(NMS 241/1)

Spec Limits
(NMS 241/2)

Spec Limits
(NMS 241/3)

Fiber Spec
(NMS 241/1F)

Fiber Spec
(NMS 241/2F)

Fiber Spec
(NMS 241/3F)
Specification Series

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 Lovingfores (NCAMP/NIAR)
Reviewed by: Rachael Andruonis (NCAMP/NIAR), Vera Richter (Teljin Carbon), Joe Spangler (Teljin Carbon), Alfonso Lopez (Teljin Carbon), Gary Fidd (Solvay)

Fabrication of NMS 240 Qualification, Equivalency, and Acceptance Test Panels
Vacuum Assisted Resin Transfer Molding
Solvay PRISM™ EP2400 toughened epoxy resin

Prepared by: Royal Lovingfores (NCAMP/NIAR), Michelle Man (NCAMP)
Reviewed by: Ric Abbott (NCAMP AER), Ed Hooper (NCAMP AER), Rachael Andruonis (NCAMP/NIAR), Adam Arnold (Finer Dynamics), Vera Richter (Teljin Carbon), Johannes Schubert (Teljin Carbon), Joe Spangler (Teljin Carbon), Alfonso Lopez (Teljin Carbon), Gary Fidd (Solvay)

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

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

FOR TEST USE ONLY

PRISM™ EP 2400 Toughened Epoxy Resin

Prepared by: Michelle Man (NCAMP), Royal Lovelingsess (NCAMP/NIAR), John Tomblin (NCAMP/NIAR)
Reviewed by: Rachael Andruskas (NCAMP/NIAR), Big Abbott (NCAMP AER), Ed Hooper (NCAMP AER), Gary Igel (Sakur)

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

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

Prepared by: Michelle Man (NCAMP), Royal Lovelingsess (NCAMP/NIAR), John Tomblin (NCAMP/NIAR)
Reviewed by: Rachael Andruskas (NCAMP/NIAR), Big Abbott (NCAMP AER), Ed Hooper (NCAMP AER), Vera Bicider (Teijin Carbon), Johannes Belzberg (Teijin Carbon), Joe Spanager (Teijin Carbon), Alfonso Lopez (Teijin Carbon)

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

National Center for Advanced Materials Performance
Wichita State University – NIAR
1845 Fairmount Ave., Wichita, KS 67208-0963, USA
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
  • 2\textsuperscript{nd} hard layup (limited methods)
  • -65°F, RTD, 180°F, 250°F
## Test Plan – Lamina (BA)

<table>
<thead>
<tr>
<th>Fiber Layup</th>
<th>Test direction</th>
<th>Test Type</th>
<th>Property</th>
<th>Number of Batches x Number of Panels x Number of Test Specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>[0/90]_4S</td>
<td>0°</td>
<td>ASTM D3039 Tension</td>
<td>Strength, Modulus, and Poisson’s Ratio</td>
<td>CTD (4) 3x2x3 RTD 3x2x3 (3) ETD 1x2x3 ETW2 3x2x3</td>
</tr>
<tr>
<td>[0/90]_4S</td>
<td>0°</td>
<td>ASTM D6641 Compression</td>
<td>Strength and Modulus</td>
<td></td>
</tr>
<tr>
<td>[0/90]_4S</td>
<td>90°</td>
<td>ASTM D3039 Tension</td>
<td>Strength and Modulus</td>
<td>CTD (4) 3x2x3 RTD 3x2x3 (1) ETD 1x2x3 ETW2 3x2x3</td>
</tr>
<tr>
<td>[0/90]_4S</td>
<td>90°</td>
<td>ASTM D6641 Compression</td>
<td>Strength and Modulus</td>
<td></td>
</tr>
<tr>
<td>[45/-45]_3S</td>
<td>0° (rotated out of 0/90 and 90/0)</td>
<td>ASTM D3518 In-Plane Shear (2)</td>
<td>Strength and Modulus</td>
<td>CTD (4) 3x2x3 RTD 3x2x3 (3) ETD 1x2x3 ETW2 3x2x3</td>
</tr>
<tr>
<td>[0/90]_4S</td>
<td>0°</td>
<td>ASTM D2344 Short Beam</td>
<td>Strength</td>
<td>CTD (4) 3x2x3 RTD 3x2x3 (3) ETD 1x2x3 ETW2 3x2x3</td>
</tr>
</tbody>
</table>
# Test Plan – Lamina (UD)

<table>
<thead>
<tr>
<th>Fiber Layup</th>
<th>Test direction</th>
<th>Test Type</th>
<th>Property</th>
<th>Number of Batches x Number of Panels x Number of Test Specimens</th>
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<tr>
<td>[0/90]_{4s}</td>
<td>0°</td>
<td>ASTM D3039 Tension</td>
<td>Strength, Modulus, and Poisson’s Ratio</td>
<td>CTD (4)</td>
</tr>
<tr>
<td>[0/90]_{4s}</td>
<td>0°</td>
<td>ASTM D6641 Compression</td>
<td>Strength and Modulus</td>
<td>3x2x3</td>
</tr>
<tr>
<td>[0]_{8}</td>
<td>0°</td>
<td>ASTM D3039 Tension</td>
<td>Strength and Modulus</td>
<td>3x2x3</td>
</tr>
<tr>
<td>[0]_{8}</td>
<td>0°</td>
<td>ASTM D6641 Compression</td>
<td>Modulus</td>
<td>3x2x3</td>
</tr>
<tr>
<td>[45/-45]_{3s}</td>
<td>0°</td>
<td>ASTM D3518 In-Plane Shear (2)</td>
<td>Strength and Modulus</td>
<td>3x2x3</td>
</tr>
<tr>
<td>[0]_{32}</td>
<td>0°</td>
<td>ASTM D2344 Short Beam</td>
<td>Strength</td>
<td>3x2x3</td>
</tr>
</tbody>
</table>
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?