# Advanced Fiber Reinforced Polymer Materials Guidelines for Aircraft Design Certification Process

Federal Aviation Administration


Presented by:

**Rachael Andrulonis**

**Royal Lovingfoss**

WSU-NIAR


JAMS

Joint Centers of Excellence for Advanced Materials

NIAR® Wichita State University National Institute for Aviation Research

A Center of Excellence AMTAS Advanced Materials in Transport Aircraft Structures

CECAM center of excellence for composites and advanced materials

JAMS Technical Review

September 29, 2021

# Introduction

- **Title**: Discontinuous Fiber Thermoplastic Polymer Composite Materials Guidance for Aircraft Design Certification Process and Control
- **Project Participants**
  - John Tomblin – Executive Director
  - Royal Lovingfoss – NCAMP Director
  - Rachael Andrulonis – Sr. Research Engineer
- **FAA Technical Monitor** – Curtis Davies
- **Other FAA Personnel** – Cindy Ashforth (primary), Several others involved
- **Industry Partnerships/Other Collaborations** – University of Washington, Solvay, Sekisui, Several through industry participants and Steering Committees
- Source of matching contribution for the current award – Kansas Aviation Research and Technology (KART)

# Advanced Fiber Reinforced Polymer Materials Guidelines for Aircraft Design Certification Process

Wichita State University
National Institute for Aviation Research

## Overall Goals

- Develop a framework for the qualification of new and innovative **thermoplastic** 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.

## Research Outputs

- **Trial tests** provide valuable lessons learned on temperature effects of key mechanical properties, test methods best suited for thermoplastic composites and effects of key process parameters
- **First public qualification** of a continuous fiber thermoplastic composite with material and process specifications
- Key aspects of **material and process control** documented
- Lessons learned, guidelines, and data made available to **CMH-17**
- **Qualification framework for chopped fiber** thermoplastic composites

**TASK 1:** Survey & Establish Steering Committee → **TASK 2:** Develop Qualification Framework → **TASK 3:** Validate framework with selected materials → **TASK 4:** Establish statistical guidelines → **TASK 5:** Transition - Material property data - Guidelines

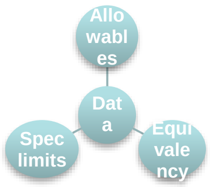
### Qualification Program Status

**Material** selected based on industry input:
*Continuous Fiber Thermoplastic*

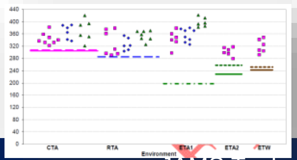
- Toray - TC1225 unidirectional tape
- Thermoplastic semi-crystalline engineered polyaryletherketone resin

**Status**:

- Screening trials and full qualification now complete
- All documents have been reviewed by Industry Steering Committee and were released in 2020
- Equivalencies on unsized fiber and continuous compression molding process are underway




*Statistical Allowables Generated*



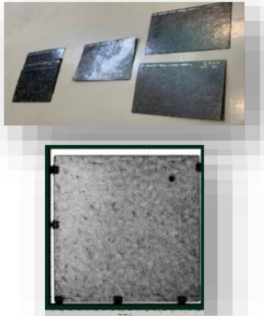

### Discontinuous Fiber Trials Status (Pre-Qualification)

**Objectives**:

- Coordinate with industry experts to develop a set of trial tests for multiple chopped fiber forms
- Develop a framework for future qualification of chopped fiber composites

**Status**:

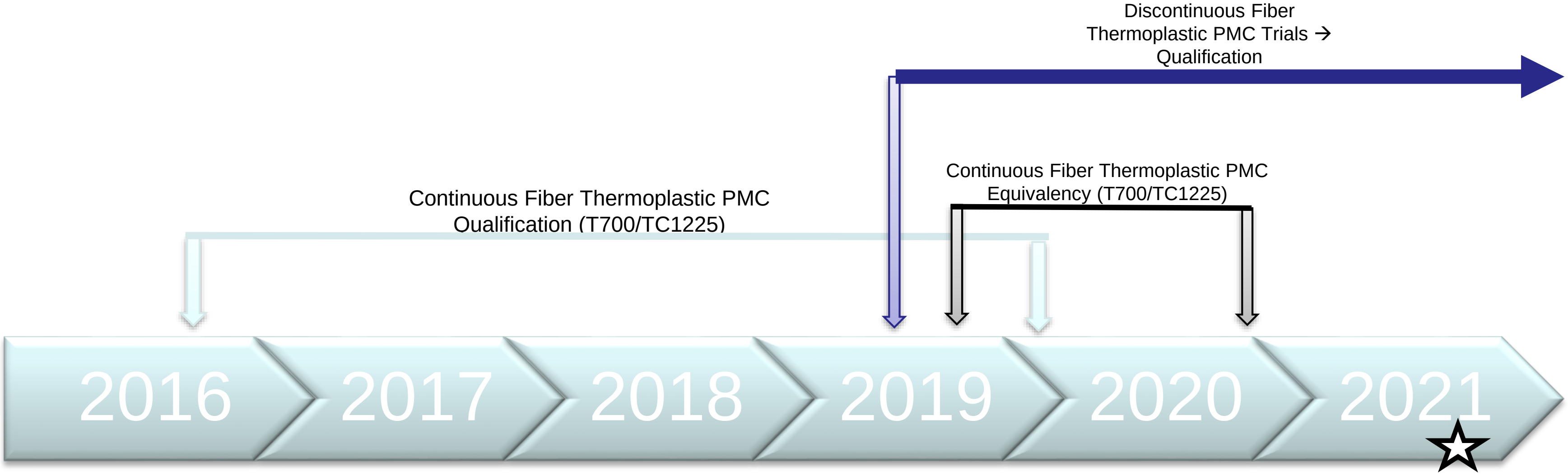
- Preliminary screening trials were completed
- Multiple thicknesses and chip sizes included in the trials
- Additional trials are currently being scoped



*Trial panels and C-Scan example*

JAMS
Joint Centers of Excellence for Advanced Materials

# Calendar Year Schedule



# Technical Approach

- Develop a framework to advance thermoplastic DFC materials into the aerospace industry.
- Utilize the experience and framework of the NCAMP composite program as an example of process sensitive material characterization.
  - For more info on NCAMP: https://www.wichita.edu/research/NIAR/Research/ncamp.php

**May 2020** → **Q2 2022** → **Q2 2023** → **Q3 2023**

Establish Steering Committee → **Develop Qualification Framework (trials)** → Perform Qualification → Establish statistical guidelines → Transition
- Material property data
- Guidelines

# DFC Trials

Preliminary Trials → Material Selection → Test Types and Geometries → Key Process Parameters → Test Matrix

# Preliminary Trials

- **Three Suppliers**
- **Thermoplastic discontinuous composites**
- **All using Chip size: 0.5” x 0.5”**
- **12” x 12’ panels**
- **C-Scan**
- **Density and void content**
- **Mechanical Properties at CTA, RTA, 250F/A and 180F/W**
  - Tension
  - Compression
  - In-Plane Shear
  - Short Beam Shear
  - Flexure
  - Bearing
  - Compression After Impact

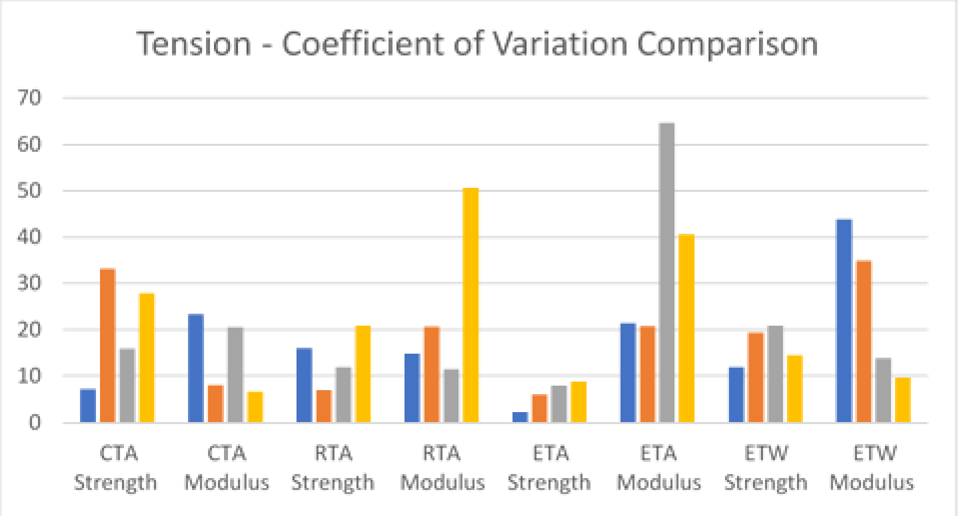
# Example Results - Tension

**TENSION - ASTM D3039-17**

**TENSILE PROPERTIES OF POLYMER MATRIX COMPOSITE MATERIALS**

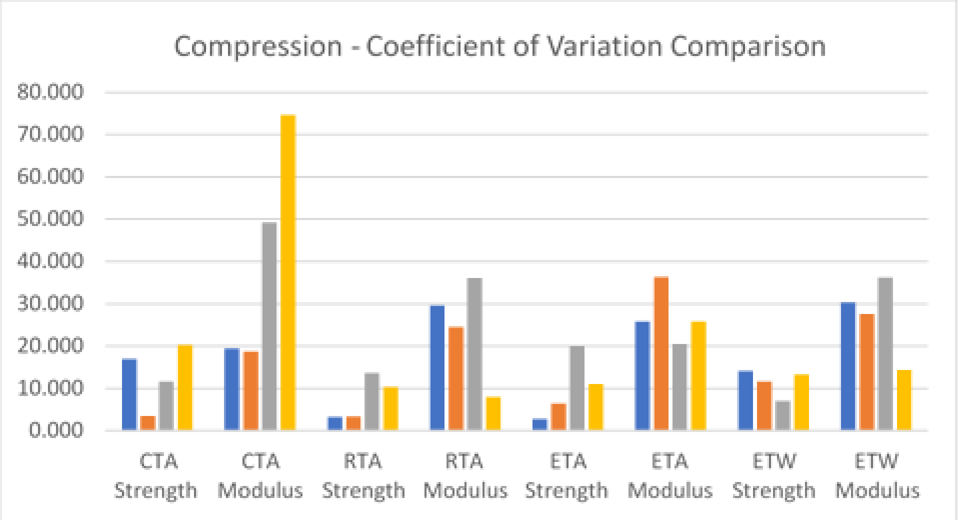
| | | | **CTA** | | **RTA** | | **250F/A** | | **180F/W** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ultimate Strength [ksi] | Modulus [Msi] | Ultimate Strength [ksi] | Modulus [Msi] | Ultimate Strength [ksi] | Modulus [Msi] | Ultimate Strength [ksi] | Modulus [Msi] |
| Supplier 1 | TRIAL 1 | Mean | **29.237** | **6.371** | **30.063** | **6.138** | **31.535** | **5.685** | **28.998** | **5.356** |
| | | CV | 7.276 | 23.339 | 16.024 | 14.822 | 2.312 | 21.448 | 11.915 | 43.934 |
| Supplier 1 | TRIAL 2 | Mean | **33.201** | **8.003** | **40.866** | **5.957** | **36.459** | **5.256** | **36.262** | **6.027** |
| | | CV | 15.990 | 20.479 | 7.096 | 20.705 | 6.125 | 20.803 | 19.394 | 34.920 |
| Supplier 2 | TRIAL 1 | Mean | **27.907** | **6.749** | **33.631** | **5.184** | **27.857** | **7.827** | **22.787** | 4.797 |
| | | CV | 22.625 | 37.866 | 11.911 | 11.507 | 7.961 | 64.662 | 20.844 | 13.905 |
| Supplier 3 | TRIAL 2 | Mean | **25.270** | **5.958** | **23.959** | **6.832** | **28.575** | **6.791** | **29.477** | **5.020** |
| | | CV | 9.669 | 19.948 | 20.849 | 50.676 | 8.774 | 40.646 | 14.536 | 9.614 |

# Tension Results



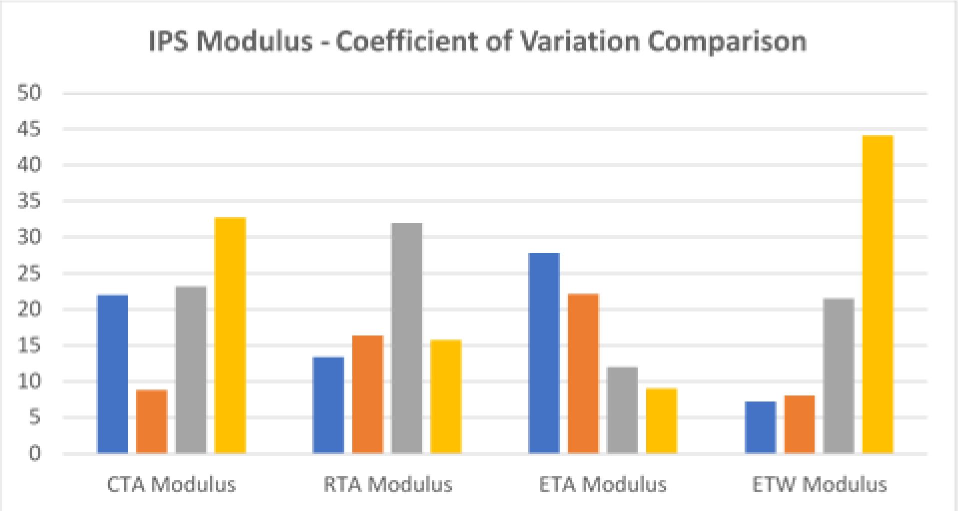

| Supplier & Trial | Average CV [%] |
|---|---|
| Supplier 1 Trial 1 | **17.634** |
| Supplier 1 Trial 2 | **18.781** |
| Supplier 2 | **20.907** |
| Supplier 3 | **22.469** |

# Compression Results



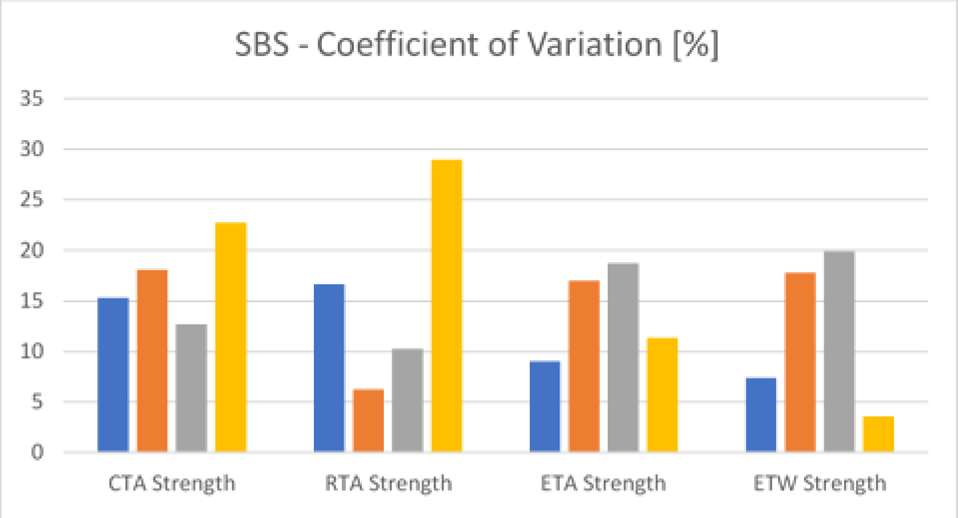

| Supplier & Trial | Average CV [%] |
|---|---|
| Supplier 1 Trial 1 | **17.772** |
| Supplier 1 Trial 2 | **16.513** |
| Supplier 2 | **24.264** |
| Supplier 3 | **22.222** |

# In-Plane Shear Results



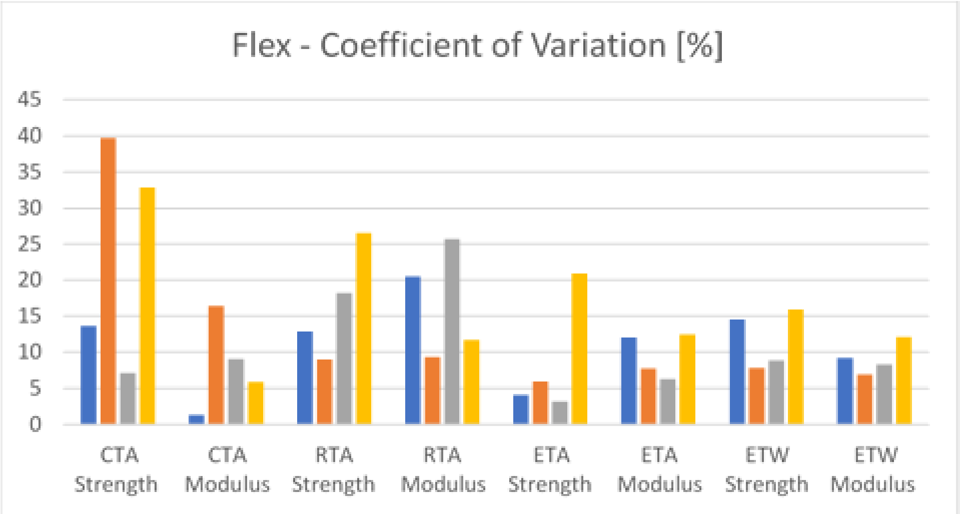

| Supplier & Trial | Average CV [%] |
|---|---|
| Supplier 1 Trial 1 | **17.597** |
| Supplier 1 Trial 2 | **13.860** |
| Supplier 2 | **22.184** |
| Supplier 3 | **25.402** |

# Short Beam Shear Test Results



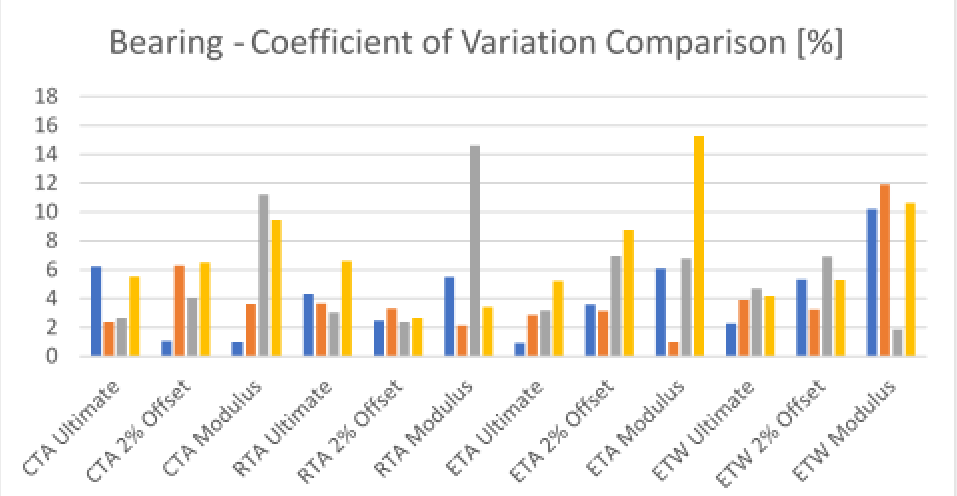

| Supplier & Trial | Average CV [%] |
| --- | --- |
| Supplier 1 Trial 1 | **12.099** |
| Supplier 1 Trial 2 | **14.776** |
| Supplier 2 | **15.397** |
| Supplier 3 | **16.670** |

# Flexure Test Results

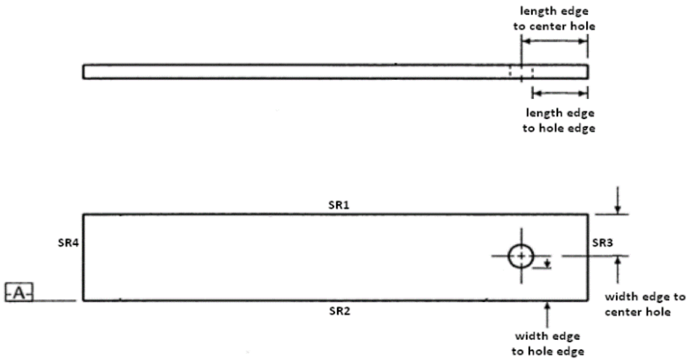



| Supplier & Trial | Average CV [%] |
|---|---|
| Supplier 1 Trial 1 | **11.008** |
| Supplier 1 Trial 2 | **12.840** |
| Supplier 2 | **10.816** |
| Supplier 3 | **17.297** |

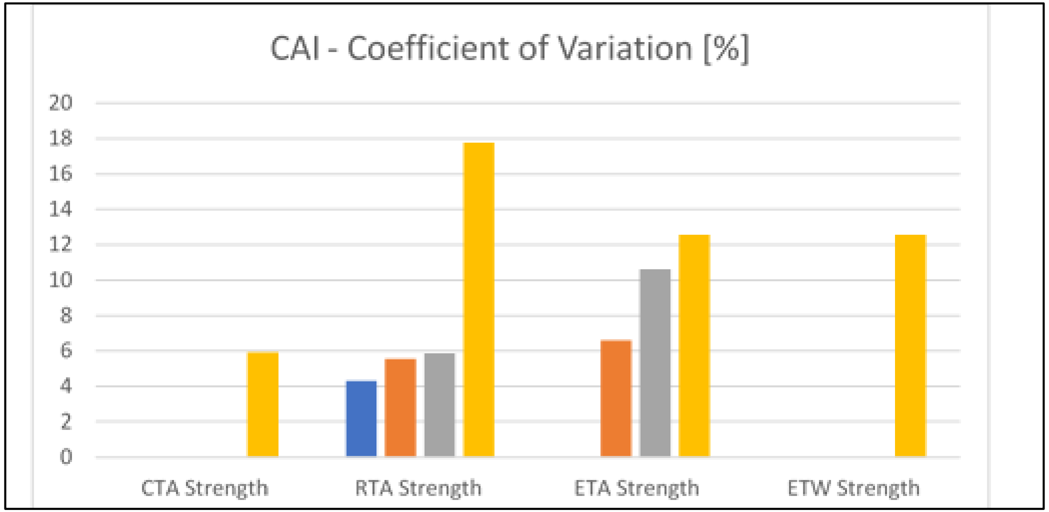
# Bearing Test Results




| Supplier & Trial | Average CV [%] |
|---|---|
| Supplier 1 Trial 1 | **4.079** |
| Supplier 1 Trial 2 | **3.959** |
| Supplier 2 | **5.697** |
| Supplier 3 | **6.962** |



# CAI Results




| Supplier & Trial | Average CV [%] |
| --- | --- |
| Supplier 1 Trial 1 | **1.079** |
| Supplier 1 Trial 2 | **3.043** |
| Supplier 2 | **4.125** |
| Supplier 3 | **12.202** |

# Material Selection Considerations



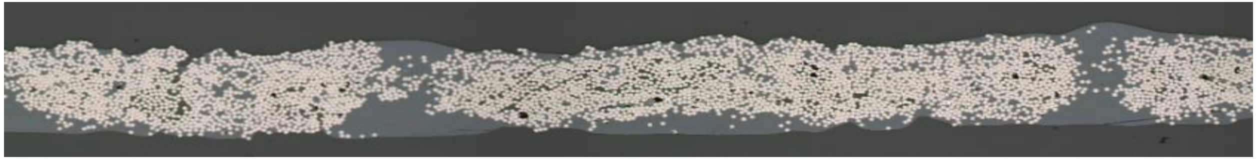
- **Synergy with JAMS partner UW**
  - Characterizing the same material will provide a more complete data set and opportunities for developing guidelines documents
- **Consistent quality**
  - C-Scan results
- **Coefficient of variation**
  - Very high across all materials for many test methods
  - Supplier 1 overall had lower CV
- **Industry relevance**
  - Material used for aerospace parts

**Same Material Selected for Both UW and NIAR Programs**

- Industry will benefit from expanded database
- Close collaboration between FAA CoE programs
- Programs will need to ensure alignment to M&P control

# Unique processing characteristics

APC Cross Section



**APC: A**romatic **P**olymer **C**omposite tapes have unique characteristics, including:

- Resin rich surface, which is a great assistance in processing
- Improved melt flow
- High level of impregnation
- Superior toughness and damage tolerance
- Excellent environmental resistance
- Capable of oven consolidation
- Extensive qualification database

**APC has unique characteristics for cost efficient part manufacturing processes**

# Chopped Fiber Thermoplastic Processing

## Industry Partner: Sekisui

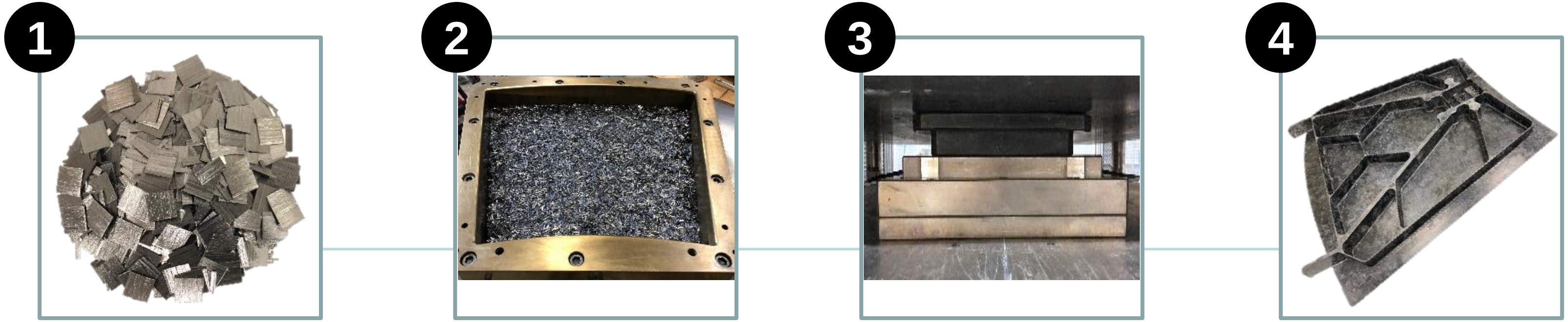
Federal Aviation Administration

JAMS
Joint Centers of Excellence for Advanced Materials

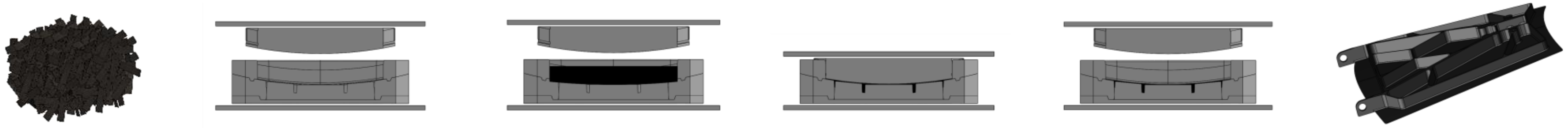
A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

CECAM
center of excellence for composites and advanced materials

# QForge® Molding Process




Preparation of Charge | Load Material | Consolidation | Finished Part

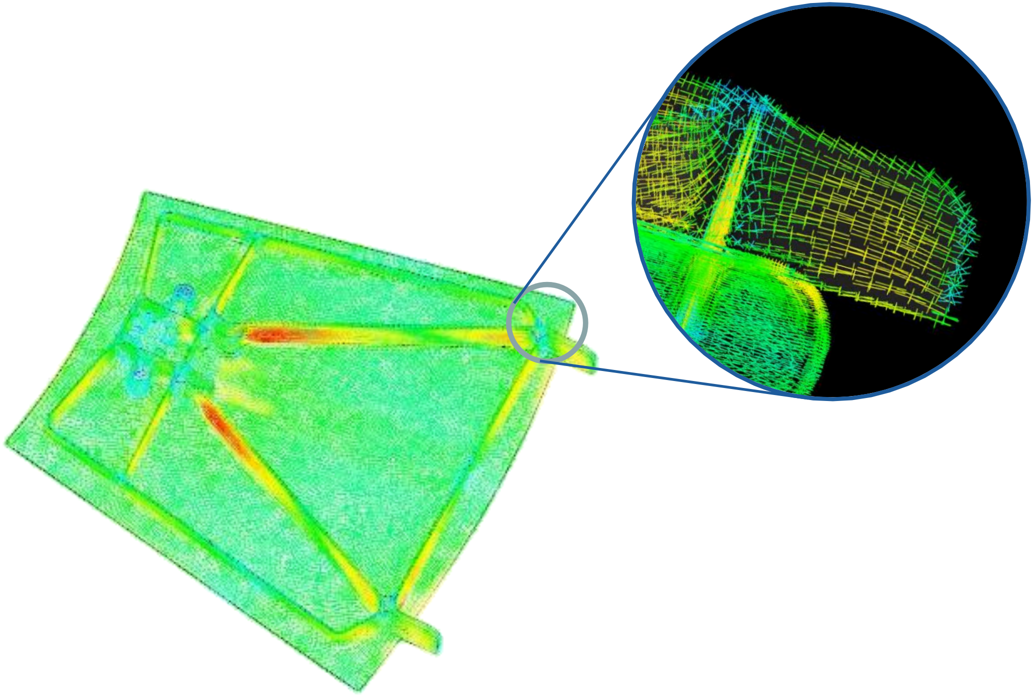


Preparation of Charge | Preparation of Mold | Place Charge Material | Consolidation Cycle (400 C, 45 bar) | Demold | Finished Part

**Molding Cycle (PEKK)**

# Tool Design and Fiber Alignment

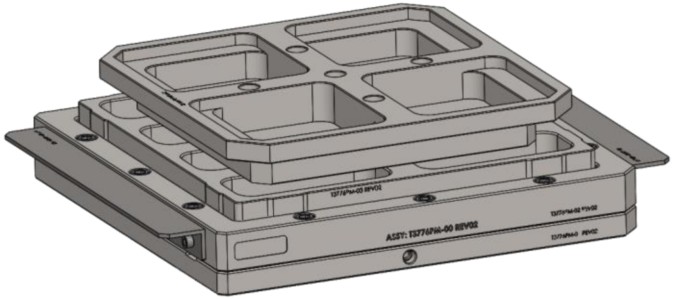
- Melt flow control can be achieved through tool design
- Able to tailor specific strengths at key structural locations by encouraging fiber alignment
- Achieve quasi-isotropic properties and encourage anisotropy where desirable based on prescribed loading conditions



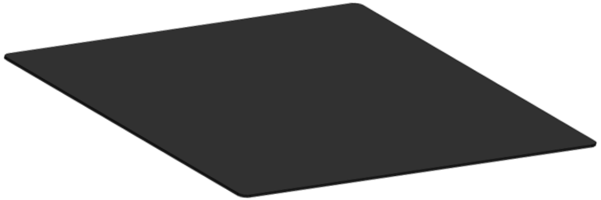
# Low Flow Tool

**Flow Characteristics: Low Flow**

- Platelets typically remain intact throughout the consolidation cycle
- The relative movement of platelets from cycle-start to -finish is negligible



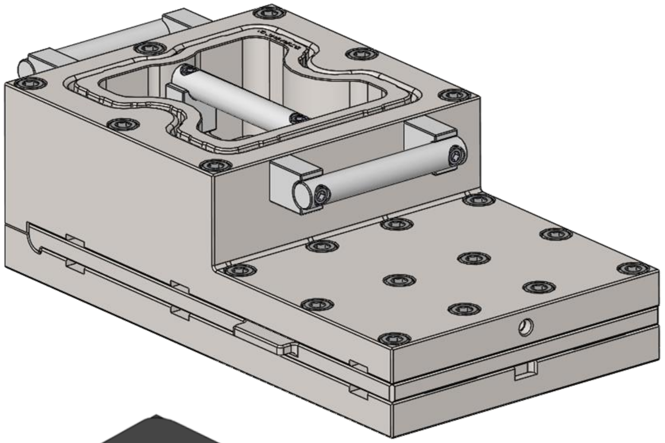
- **Panel Size: 12.125” x 12.125”**
- **Max. Thickness: .300”**
- **Min. Recommended Thickness: .070”**

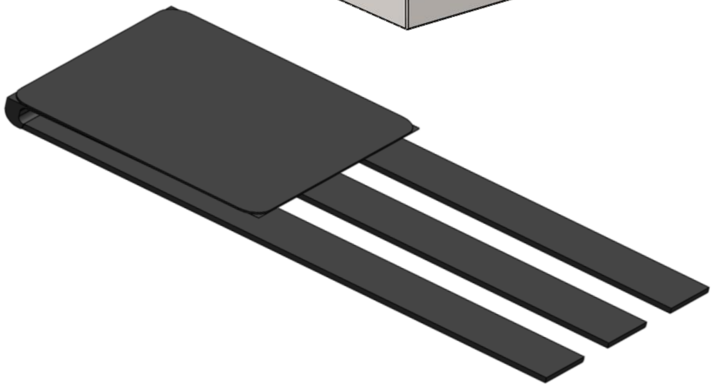


# High Flow Tool

Flow Characteristics: High Flow

- Platelets are forced from the charge cavity into the part or mold cavity
- Fibers constituting individual platelets typically disperse during pressure application and fiber alignment is dependent on the flow type (convergent or divergent)





- Coupon Size: 13.85” x 1.50” or 7” x 7”
- Min./Max. Thickness: .150”
- The addition of shims into coupon cavity can allow for thinner coupons

# Goals of Trials

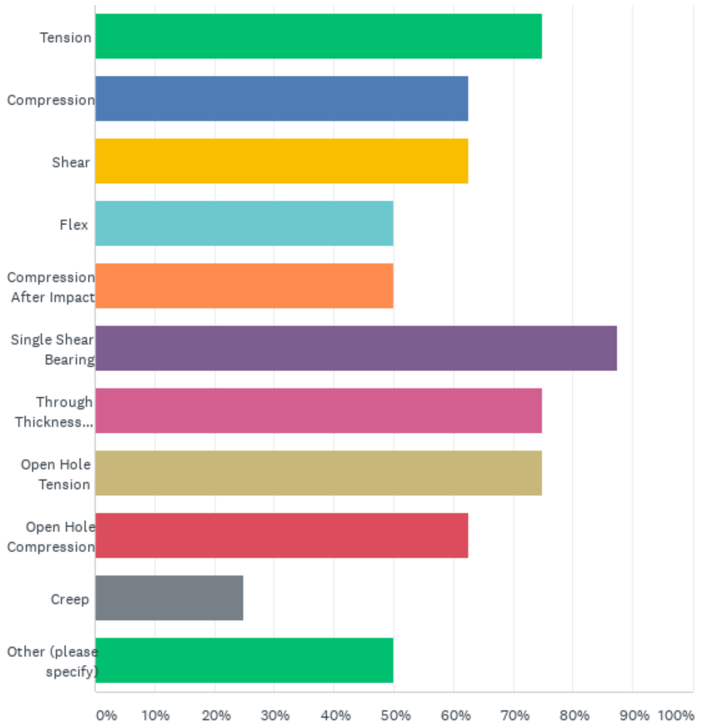
- Critical for success of subsequent qualification that provides value to industry
- Understand the effects of key processing parameters to establish a robust processing specification
- Understand variability and how many specimens are needed
- Understand failure modes and size effects
- Test methods – which ones will give appropriate failure modes consistently, which ones need to be modified
- Test temperatures – does moisture conditioning degrade properties? what is the max use temperature and what temperatures should allowables be derived?
- What information should be included in a material specification and process specification?

# DFC Trial Test Matrix – Survey Results

- **Wednesday, May 19, 2021**

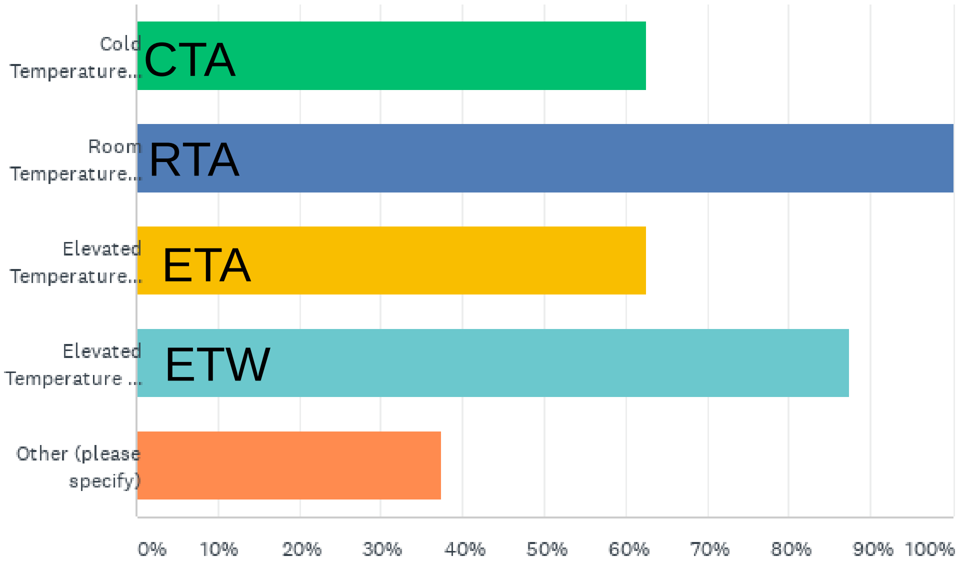
Powered by SurveyMonkey

# Q1: Please check off properties of interest for the trial test matrix:



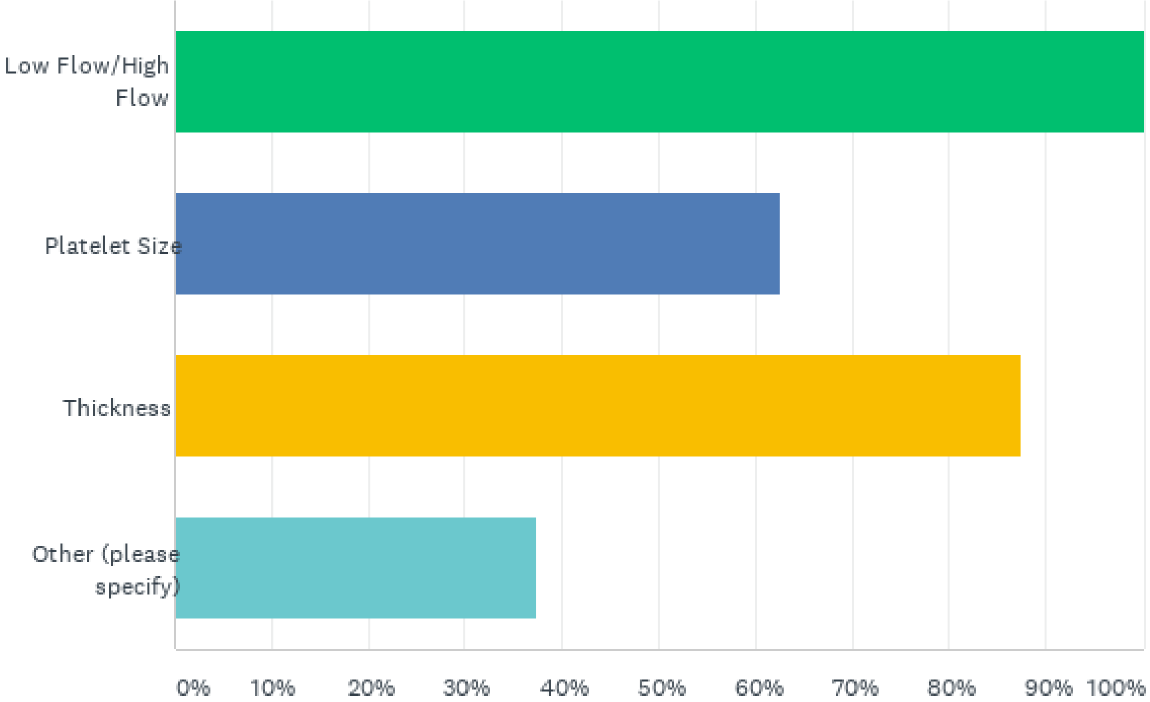

| |
|---|
| Further characterization of size effects (W/D), where D is hole or other damage size metrics, and inhomogeneous microstructure.<br><br>Also consider DIC investigations that show how stress concentrations are interacting with specimen geometry. |
| - Thru-Thickness Tension should be done with the curved beam ASTM D6415 type test<br><br>- Also need some tension tests for a) range of thicknesses, b) comparing specimen machined from larger panel vs net molded specimens |
| Ensure all specimens have width at least 1.5 times largest platelet dimension (including diagonal). |
| finite hole size effects, e.g., OHT at D = 0.375, 0.50, 0.75, 1.00, etc. |

# Q2: The following conditions are planned for the next set of trials. Please indicate which conditions are of interest:




| |
|---|
| add -65F if a property is more critical vs RTA; add 240F/amb, 300F/amb; add 240F/wet and 300F/wet if previous data shows wet effect is significant |
| 250°F ambient - Needed for engine applications |
| ETW at T = wet Tg - 50F |

# Q3: Please indicate which parameters you would like to see evaluated in the trials:




| |
|---|
| Comparisons of properties from specimen machined from larger panel vs properties from net molded specimens. |
| Platelet size of 0.5"x0.5" seems most common in industry and should be selected for all trials. |
| molded 90-deg flanges; tension-fitting sub-elements; lug sub-elements |

# Other Survey Comments

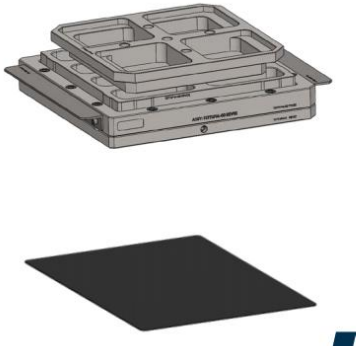
| |
|---|
| As stated before, need to come up with some generic-ish 3D geometry parts that can be used to validate analysis methods using material properties from flat coupons.  Tee-joint fittings; bathtub fittings, etc. |
| For high flow condition, need to investigate through thickness variation in fiber alignment due to skin-core-skin effects (flow shear effects) & effect of thickness on this. |

## Low Flow Tool

Flow Characteristics: Low Flow

- Platelets typically remain intact throughout the consolidation cycle
- The relative movement of platelets from cycle-start to -finish is negligible

- Panel Size: 12.125” x 12.125”
- Max. Thickness: .300”
- Min. Recommended Thickness: .070”

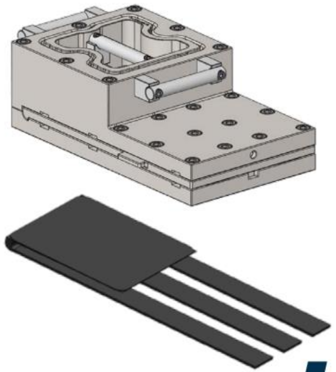


## High Flow Tool

Flow Characteristics: High Flow

- Platelets are forced from the charge cavity into the part or mold cavity
- Fibers constituting individual platelets typically disperse during pressure application and fiber alignment is dependent on the flow type (convergent or divergent)

- Coupon Size: 13.85” x 1.50”
- Min./Max. Thickness: .150”
- The addition of shims into coupon cavity can allow for thinner coupons



SEKISUI

# Discussion Topics

- **Tension: ASTM D3039/D638**
  - For D3039 vs D638, it seems that industry recommends D638 for discontinuous fiber composites as strain gauges are not of much value for discontinuous fiber.
  - D638 – will need to use extensometers to gather modulus data, the only drawback is that we can't get ultimate strain with an extensometer.
  - Consider D3039 with DIC
- **Through Thickness Tension: D6415**
  - There are many differences between high and low flow, but one major difference is the fiber orientation through the thickness of the coupon/component; with low flow being resin dominate through thickness and high flow being more "isotropic".
  - There may being other standards for quantifying this difference.
- **Creep**
  - Elevated temperature creep in tension properties – this has been a question for multiple potential applications.
  - This test can also be added as additional information, but not for deriving B-basis allowables.
  - Not much interest in the survey

# Discussion Topics

- **Coupon Widths**
  - Coupons widths to accommodate a “flakes” full length (fiber direction) should only be of concern for low flow coupons where the flakes and fibers maintain their original shape during the consolidation cycle.
  - Best to treat low flow and high flow with the same methods.
- **Platelet Size**
  - Stick with industry standard 0.5 x 0.5 inch for trials?
  - Options: 0.5 x 1/16 in. or 0.5 x 0.5 in. square
- **Thickness**
  - The thickness effect saturates after 0.15". Recommend 0.1" and 0.15" range.
  - UW tested a 0.065" thickness, which showed lower strength and higher variability.

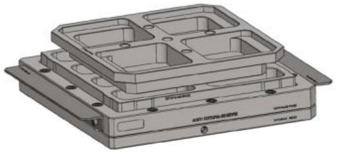
# Parameters of Interest

- Flow
- Platelet Size
- Thickness

## Low Flow Tool

Flow Characteristics: Low Flow

- Platelets typically remain intact throughout the consolidation cycle
- The relative movement of platelets from cycle-start to -finish is negligible

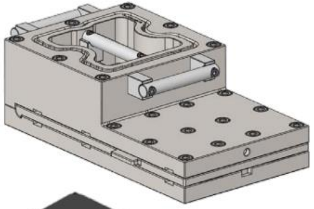


- Panel Size: 12.125” x 12.125”
- Max. Thickness: .300”
- Min. Recommended Thickness: .070”

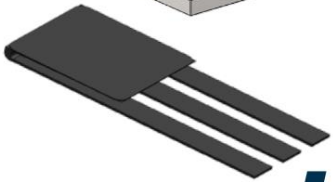
## High Flow Tool

Flow Characteristics: High Flow

- Platelets are forced from the charge cavity into the part or mold cavity
- Fibers constituting individual platelets typically disperse during pressure application and fiber alignment is dependent on the flow type (convergent or divergent)



- Coupon Size: 13.85” x 1.50” Or 7” x 7”
- Min./Max. Thickness: .150”
- The addition of shims into coupon cavity can allow for thinner coupons



SEKISUI

JAMS Joint Centers of Excellence for Advanced Materials

# Test Iterations

NIAR WICHITA STATE UNIVERSITY
NATIONAL INSTITUTE FOR AVIATION RESEARCH

| Iteration | Flow | Thickness | Platelet Size |
|---|---|---|---|
| 1 | High | Thickness 1 | Platelet Size 1 |
| 2 | High | Thickness 1 | Platelet Size 2 |
| 3 | High | Thickness 2 | Platelet Size 1 |
| 4 | High | Thickness 2 | Platelet Size 2 |
| 5 | Low | Thickness 1 | Platelet Size 1 |
| 6 | Low | Thickness 1 | Platelet Size 2 |
| 7 | Low | Thickness 2 | Platelet Size 1 |
| 8 | Low | Thickness 2 | Platelet Size 2 |

Cannot do this combination (grey): iterations 1, 2
Reduced Matrix (green): iterations 3, 5, 6, 7
Full Matrix (yellow): iterations 4, 8

Thickness 1 = 0.250 in
Thickness 2 = 0.150 in
Platelet Size 1 = 0.5 x 1/16 in
Platelet Size 2 = 0.5 x 0.5 in

Low Flow - 12" x 12" panel, longitudinal or transverse does not matter, thickness is 0.075 to 0.300 inch.

High Flow - 13" x 1.5" panel, longitudinal, thickness is only 0.150 inch.

High Flow - 7" x 7" panel, transverse, thickness is only 0.150 inch.

# Full Matrix – High Flow

Wichita State University
National Institute for Aviation Research

**Mechanical Test Matrix (Optimized Iteration) - High Flow (0.150") (Platelet 0.5" x 0.5")**

| Test Type | Orientation | Test Method (2) | CTA (-65F) | RTA | 180F/A | 180F/W | 350F/A | 350F/W |
|---|---|---|---|---|---|---|---|---|
| Tension | Long to flow | ASTM D3039 (DIC at RT) | 6 | 6 | 6 | 6 | 6 | 6 |
| Tension | Transverse to flow | ASTM D3039 (DIC at RT) | 6 | 6 | 6 | 6 | 6 | 6 |
| Compression | Long to flow | ASTM D6484 with no hole /D3410 | 6 | 6 | 6 | 6 | 6 | 6 |
| Compression | Transverse to flow | ASTM D6484 with no hole / D3410 | 6 | 6 | 6 | 6 | 6 | 6 |
| Shear | Long to flow | ASTM D7078 / D5379 | | 6 | | | | |
| Shear | Transverse to flow | ASTM D7078 / D5379 | | 6 | | | | |
| Flex | Long to flow | ASTM D7264 | | 6 | | | | |
| Flex | Transverse to flow | ASTM D7264 | | 6 | | | | |
| Open Hole Tension | Long to flow | ASTM D5766, hole size 1 (TBD) | | 6 | | | | |
| Open Hole Tension | Transverse to flow | ASTM D5766, hole size 1 (TBD) | | 6 | | | | |
| Open Hole Tension | Long to flow | ASTM D5766, hole size 2 (TBD) | | 6 | | | | |
| Open Hole Tension | Transverse to flow | ASTM D5766, hole size 2 (TBD) | | 6 | | | | |
| Open Hole Tension | Long to flow | ASTM D5766, hole size 3 (TBD) | | 6 | | | | |
| Open Hole Tension | Transverse to flow | ASTM D5766, hole size 3 (TBD) | | 6 | | | | |
| Open Hole Compression | Long to flow | ASTM D6484 | | 6 | | | | |
| Open Hole Compression | Transverse to flow | ASTM D6484 | | 6 | | | | |
| Interlaminar Tension | Long to flow | ASTM D6415 | | 6 | | | | |
| Interlaminar Tension | Transverse to flow | ASTM D6415 | | 6 | | | | |
| Single Shear Bearing | Long to flow | ASTM D5961 procedure C, 0.25"d | | 6 | | | | |
| Single Shear Bearing | Transverse to flow | ASTM D5961 procedure C, 0.25"d | | 6 | | | | |
| CAI | Long to flow | ASTM D7136/D7137 | | 6 | | | | |
| CAI | Transverse to flow | ASTM D7136/D7137 | | 6 | | | | |

**Notes**

(1) Test matrices to be repeated as shown in separate tab

(2) Scale/oversize coupon so 2 or more platelet across width (may required test method deviation/modification)

Joint Centers of Excellence for Advanced Materials

# High Flow – Reduced Matrix

**Mechanical Test Matrix (Iteration 3) High Flow (0.150") (Platelet 0.5" x 0.0625")**

| Test Type | Orientation | Test Method (2) | CTA (-65F) | RTA | 180F/A | 180F/W | 350F/A | 350F/W |
|---|---|---|---|---|---|---|---|---|
| Tension | Long to flow | ASTM D3039 (DIC at RT) | | 6 | 6 | | 6 | |
| Tension | Transverse to flow | ASTM D3039 (DIC at RT) | | 6 | 6 | | 6 | |
| Compression | Long to flow | ASTM D6484 with no hole | | 6 | | | | |
| Compression | Transverse to flow | ASTM D6484 with no hole | | 6 | | | | |
| Shear | Long to flow | ASTM D7078 | | 6 | | | | |
| Shear | Transverse to flow | ASTM D7078 | | 6 | | | | |
| Open Hole Tension | Long to flow | ASTM D5766, hole size 1 (TBD) | | 6 | | | | |
| Open Hole Tension | Transverse to flow | ASTM D5766, hole size 1 (TBD) | | 6 | | | | |

# Low Flow – Reduced Matrix

WICHITA STATE UNIVERSITY
NATIONAL INSTITUTE FOR AVIATION RESEARCH

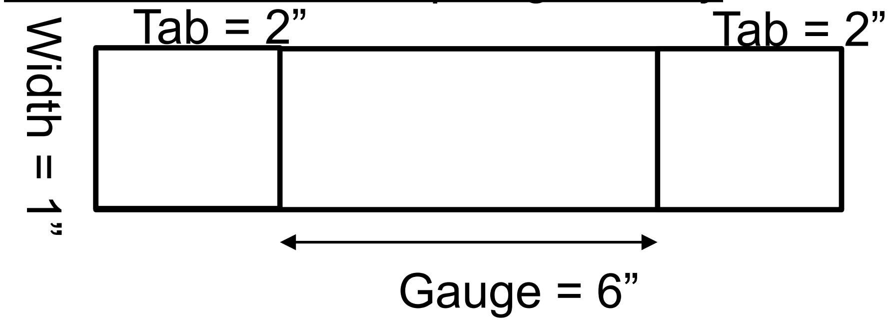
**Mechanical Test Matrix (Iteration 5) Low Flow (0.250") (Platelet 0.5" x 0.0625")**

| Test Type | Test Method (2) | CTA (-65F) | RTA | 180F/A | 180F/W | 350F/A | 350F/W |
|---|---|---|---|---|---|---|---|
| Tension | ASTM D3039 (DIC at RT) | | 6 | 6 | | 6 | |
| | | | | | | | |
| Compression | ASTM D6484 with no hole | | 6 | | | | |
| | | | | | | | |
| Shear | ASTM D7078 | | 6 | | | | |
| | | | | | | | |
| Open Hole Tension | ASTM D5766, hole size 1 (TBD) | | 6 | | | | |

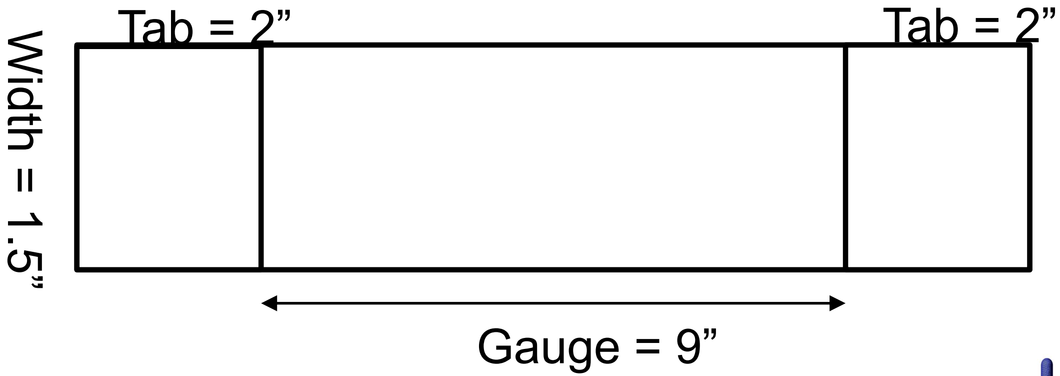
# Recommended Geometries

# Unnotched Tension (ASTM D3039)

UW tested UNT coupon geometry

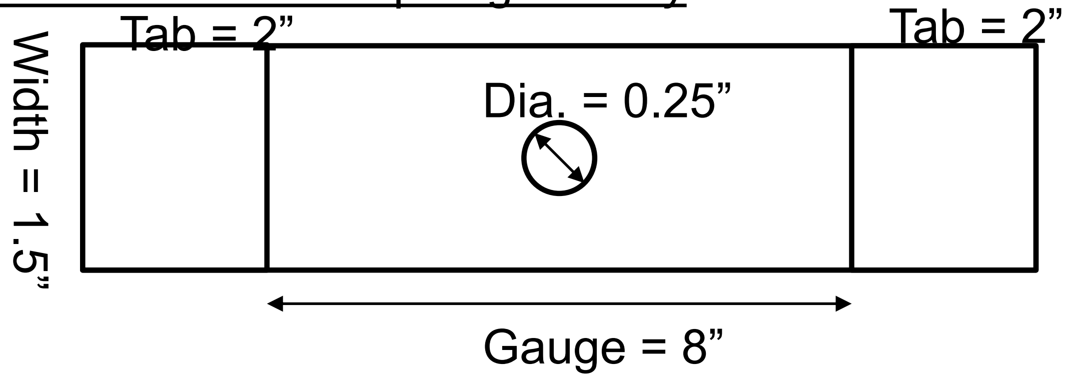



Recommended UNT coupon geometry

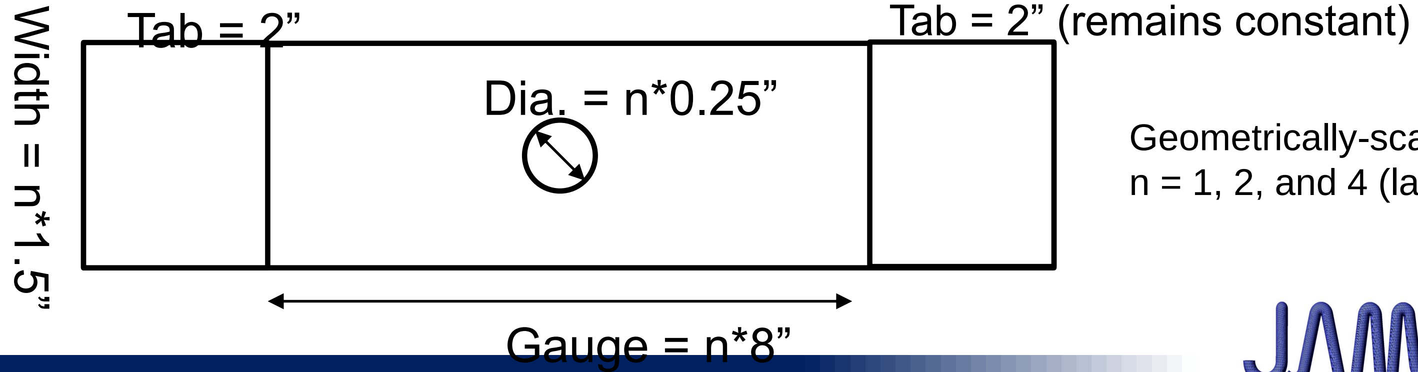


# Open Hole Tension (ASTM D5766)

UW tested OHT coupon geometry



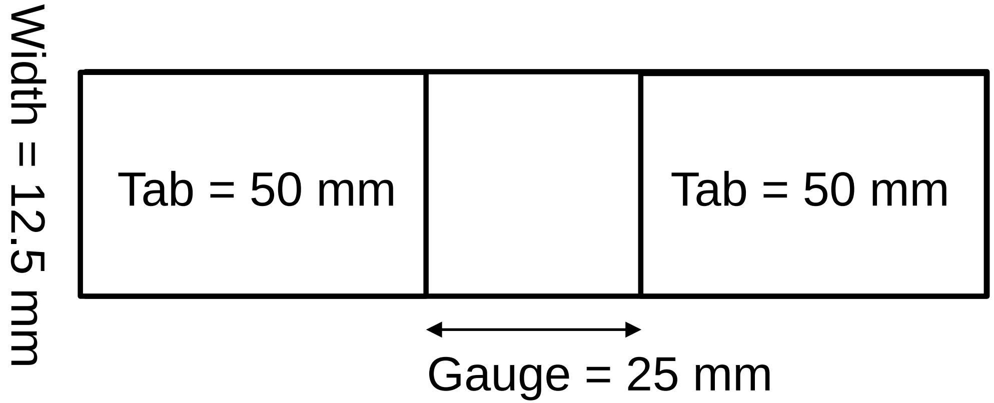

Recommended OHT coupon geometry



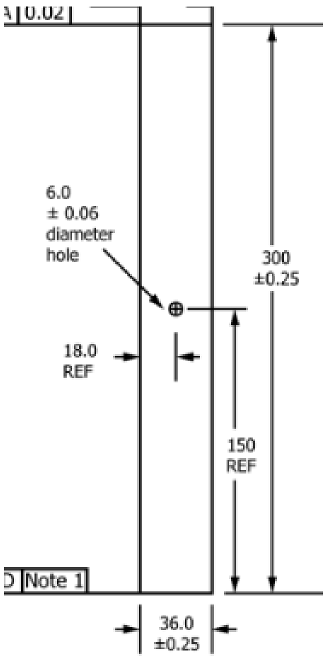

Geometrically-scaled coupons:
n = 1, 2, and 4 (larger the better)

# Compression

<u>ASTM D3410 - UW tested compression coupon geometry</u> .
Adjusted coupon geometry to fit into our existing compression fixture.
Tested thickness = 3 ~ 4 mm




## D6484 Geometry

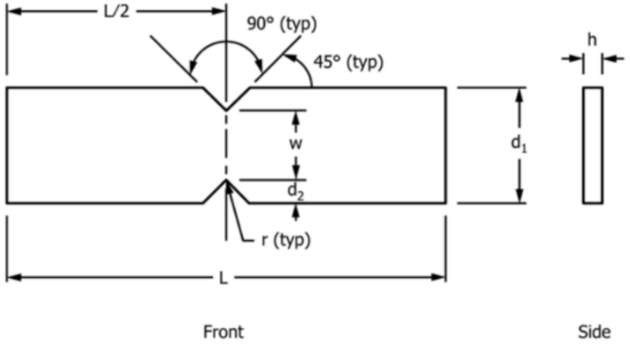



Discussion:

- The D3410 is smaller and is similar to D6641.
- NIAR has had many slippage issues with the way the fixture is designed.
- D6484 is wider and we can make sure we get at least one unit cell into the gage width.

# In-plane Shear (ASTM D5379)

UW tested D5379 shear coupon geometry.



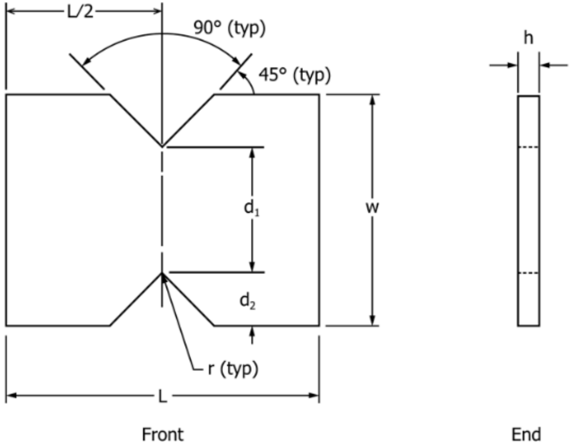

Nominal Specimen Dimensions

| | | |
|---|---|---|
| $d_1$ | = | 19 mm [0.75 in.] |
| $d_2$ | = | 3.8 mm [0.15 in.] |
| h | = | as required |
| L | = | 76 mm [3.0 in.] |
| r | = | 1.3 mm [0.05 in.] |
| w | = | 11.4 mm [0.45 in.] |

UW tested h = 3 mm.

Clamps were needed at the tabs to have a desired failure mode

## D7078




Nominal Specimen Dimensions

| | | |
|---|---|---|
| $d_1$ | = | 31.0 mm [1.20 in.] |
| $d_2$ | = | 12.7 mm [0.50 in.] |
| h | = | as required |
| L | = | 76.0 mm [3.0 in.] |
| r | = | 1.3 mm [0.05 in.] |
| w | = | 56.0 mm [2.20 in.] |

# Flexure (ASTM D7264)

## 3-pt bending coupon geometry

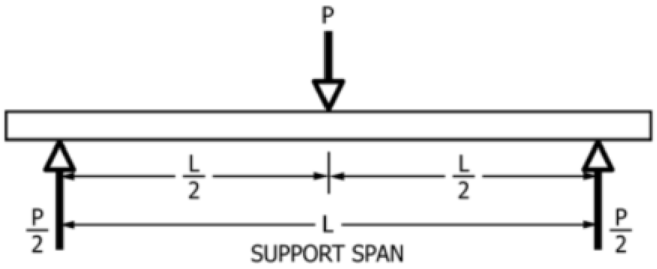


FIG. 1 Procedure A—Loading Diagram

- 32:1 span to thickness ratio
- Total length = 1.2 * span length
- Tested 3, 6, 9 mm thicknesses.
- For 3 and 6 mm thickness, width = 13 mm, supporting pins = 1/8” radius.
- For 9 mm thickness, width = 26 mm, supporting pins = 3/8” radius (due to crushing at the pins).

# Next Steps and Planned Work

- Continue to finalize test specimen geometry with University of Washington
- Work with Sekisui and Solvay to finalize trial test matrix
- Fabricate test panels
- Perform pre-qualification testing for all test requirements within:
  - NDI
  - Physical Testing
  - Mechanical Testing
  - Mechanical Design Guidance Testing
- Data reduction and reporting
- Develop framework for qualification

# Questions?

**Thank you!**