Polymer Based Additive Manufacturing Guidelines for Aircraft Design and Certification

Federal Aviation Administration

Presented by:

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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

NIAR
Wichita State University
National Institute for Aviation Research

April 18, 2023

Technical Approach

Material Qualification

- Baseline Testing Applied to Increasingly Complicated Materials
- Expand Framework to Additional AM Technologies
- Perform Equivalencies to Demonstrate Framework

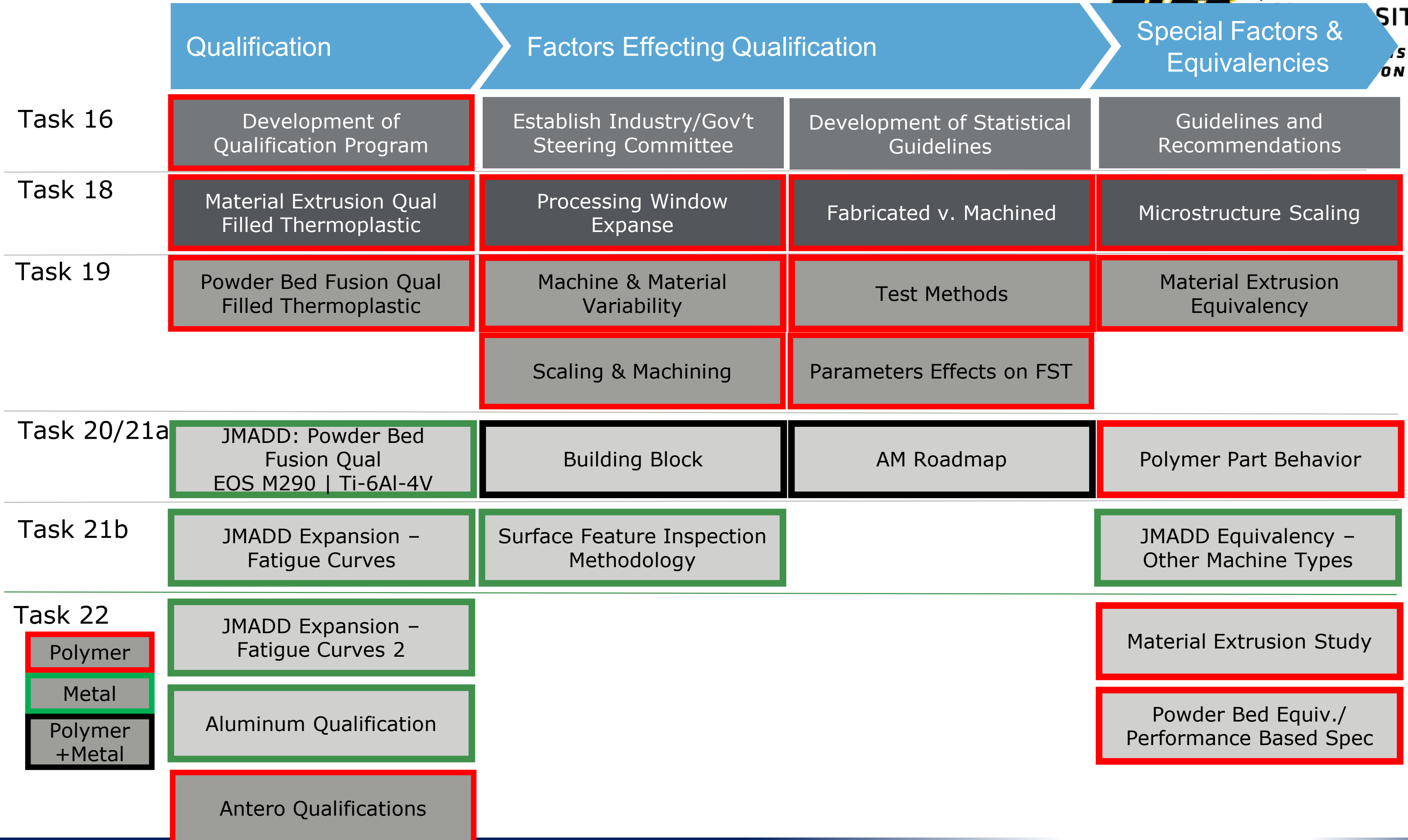
Factors Effecting Qualification

- Validate and Expand Processing Window
- FST Studies – Impact of Design
- Scaling – Specimen to Part Correlations
- Building Block – Application Specific Characterization

Pre-Qualification Considerations

- Static & Dynamic Property Behaviors
- Effect of Defects
- Machine to Machine Variability
- Within Chamber Variability

Overview of NIAR JAMS AM Tasks



	Qualification	Factors Effecting Qualification		Special Factors & Equivalencies
Task 16	Development of Qualification Program	Establish Industry/Gov't Steering Committee	Development of Statistical Guidelines	Guidelines and Recommendations
Task 18	Material Extrusion Qual Filled Thermoplastic	Processing Window Expanse	Fabricated v. Machined	Microstructure Scaling
Task 19	Powder Bed Fusion Qual Filled Thermoplastic	Machine & Material Variability	Test Methods	Material Extrusion Equivalency
		Scaling & Machining	Parameters Effects on FST	
Task 20/21a	JMADD: Powder Bed Fusion Qual EOS M290 | Ti-6Al-4V	Building Block	AM Roadmap	Polymer Part Behavior
Task 21b	JMADD Expansion – Fatigue Curves	Surface Feature Inspection Methodology		JMADD Equivalency – Other Machine Types
Task 22	JMADD Expansion – Fatigue Curves 2			Material Extrusion Study
	Aluminum Qualification			Powder Bed Equiv./ Performance Based Spec
	Antero Qualifications			

🟥 Polymer
🟩 Metal
⬛ Polymer +Metal

Ti 6-4 – M290

Ti 6-4 Reuse

CCF Onyx + X7

CCF Onyx + X7

ULTEM9085 +
Essentium 280i

HEXAM – P800

HEXAM Equiv.

Dynamic
Testing

Machining

Dynamic
Testing

Notching
Methods

ULTEM9085 + Fortus 900mc

ULTEM9085 Equiv. x2

Micro-
structure

+

Parameter
Mapping

ULTEM9085 + F900

Test Methods
Handbook Development
SDO Support

FY16

FY18

FY19

FY20

JAMS
Joint Centers of Excellence for Advanced Materials

Current Polymer AM Research

Polymer Material Extrusion with Continuous Carbon Fiber
- Markforged OFRA/CFRA qualification on a Markforged X7

Polymer laser powder bed fusion/SLS with carbon-filled ESD PEKK
- Hexcel filled PEKK qualification on EOS P800

Upcoming Qualification Projects
- NCAMP qualifications of PEKK Antero 800 and Antero 840CN03 on Stratasys F900

Building Block Feature Investigation
- Investigation of feature-level test on MEX and LPBF specimens following from ULTEM 9085 and Ti-6Al-4V quals

Roadmap
- Generation of a report detailing a snapshot of current AM MRL/TRL across industry

Research Studies/Factors Affecting Qualification
- Analysis of base level building block factors (parameter adjustment, machining, FST, scaling, etc.)

Previous Work:

Qualification of FDM/FFF/Material Extrusion using neat PEI filament polymer
- NCAMP qualification of certified ULTEM 9085 on Stratasys Fortus 900mc

Markforged - Continuous Fiber AM MEX

Background

Motivation and Key Issues

- Material qualification for Markforged’s Additively Manufactured Polymer Composite Material Onyx FR-A (OFRA) reinforced with continuous Carbon Fiber FR-A (CFRA).
- Material performance capabilities for AM composite reinforced polymer material.
- An AM material with enhanced strength performance in specific loading scenarios.
- Potential Flame Retardant performance of a Nylon base polymer material with Carbon Fiber reinforcement.

Objective and Scope

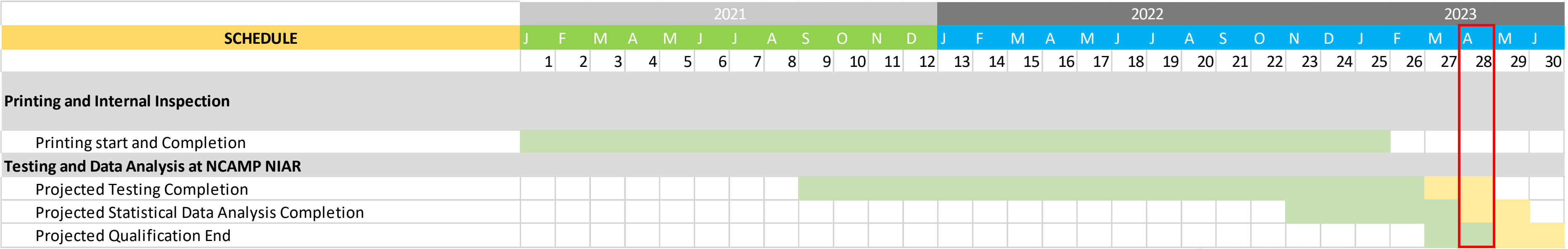
- Expand the NCAMP qualification framework for polymer AM materials to more complex materials and manufacturing methods.
- Generate publicly available material and process specifications.
- Generate full dataset including B-Basis allowables for all qualification-required test methods.
- Physical, mechanical, mechanical design guidance, fluid sensitivity, and nondestructive testing for all qualification required test methods.

Approach

- Utilize NCAMP framework to further advance AM materials into the aerospace industry as an example of process sensitive material characterization.
- NCAMP material qualification methodology and documentation
    - NTP AM-6754Q1
    - NPS 86754 Markforged Onyx-X7 Process Spec
    - NMS 754 Onyx FR-A
    - NMS 755 Carbon Fiber FR-A
    - NMS 754-1 (Slash Sheet)
- Establish Steering Committee, Develop Qualification Framework (trials), **Perform Qualification,** Establish statistical guidelines, Transition material property data

Status of Ongoing Effort

- Qualification testing is ongoing (testing to be completed in May)
- Finalizing and publishing program specification documents on NCAMP Portal.
- Reprints occurring for specimens that encountered assignable causes.
- NCAMP statistical data analysis ongoing: investigation of anomalies, compiling NCAMP summary data sheets.
    - Inconsistent data and improper failure modes will be analyzed for assignable cause to determine NCAMP acceptance.
- Projected program completion: June 30th, 2023.
- Expected publications: NCAMP reports and specifications, FAA lessons learned research report, ASTM alternative test method guidance documentation, SAE standards development from NCAMP documentation

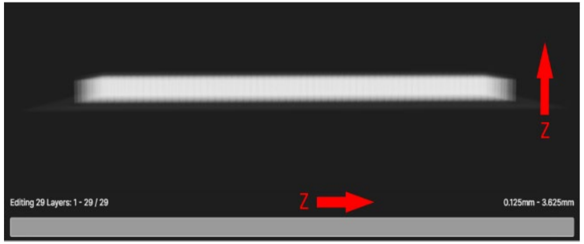


	2021												2022												2023					
SCHEDULE	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Printing and Internal Inspection																														
Printing start and Completion	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩					
Testing and Data Analysis at NCAMP NIAR																														
Projected Testing Completion									🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨		
Projected Statistical Data Analysis Completion																							🟩	🟩	🟩	🟩	🟩	🟨	🟨	
Projected Qualification End																											🟩	🟩	🟨	🟨

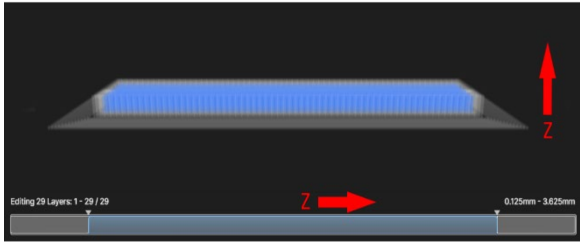
Technical Information (Fiber Fill)

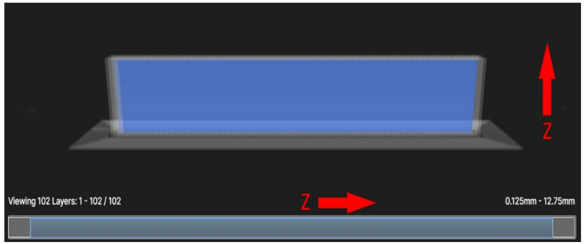
- Images shown from Markforged’s Eiger slicing software
- Specimen represented is ASTM D7028 DMA (Dynamic Mechanical Analysis) physical test specimen.
- Blue areas throughout the part geometry show where CFRA reinforcement is printed in each orientation.

No Fiber (NF)



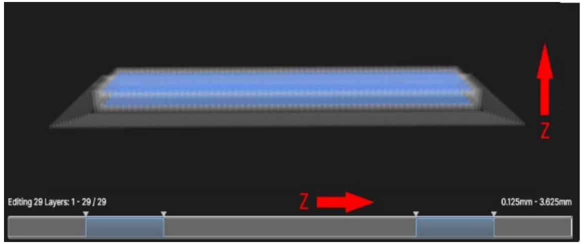
Full Fiber (FF)

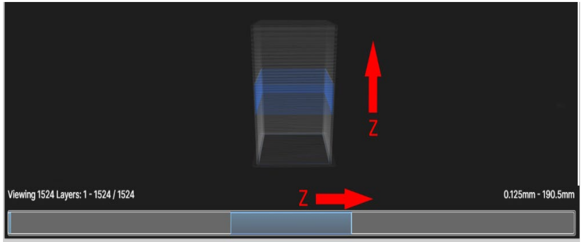




ZX

Partial Fiber (PF)

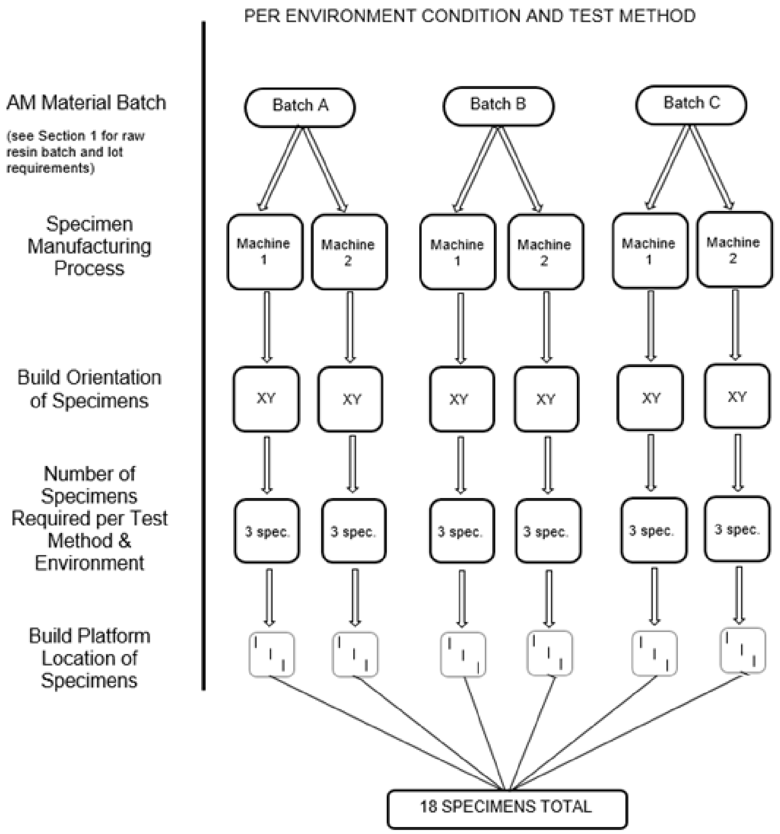




XY

XZ

Qualification Methodology



PER ENVIRONMENT CONDITION AND TEST METHOD

AM Material Batch

(see Section 1 for raw resin batch and lot requirements)

Batch A
Batch B
Batch C

Specimen Manufacturing Process

Machine 1
Machine 2
Machine 1
Machine 2
Machine 1
Machine 2

Build Orientation of Specimens

XY
XY
XY
XY
XY
XY

Number of Specimens Required per Test Method & Environment

3 spec.
3 spec.
3 spec.
3 spec.
3 spec.
3 spec.

Build Platform Location of Specimens

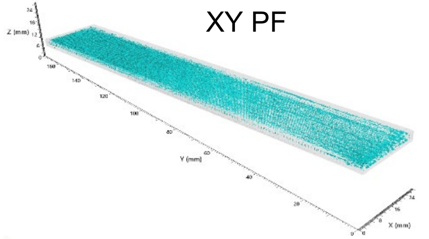
18 SPECIMENS TOTAL

Qualification Test Standards

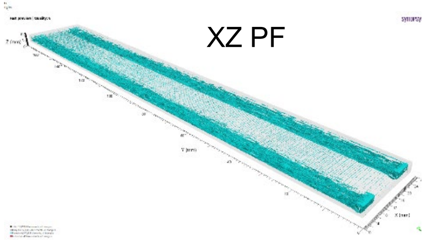
- **ASTM D256-10(2018)** – Standard Test Methods for Determining the IZOD Pendulum Impact Resistance of Plastics
- **ASTM D790-17** – Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
- **ASTM D792- 20** – Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
- **ASTM D2344/D2344M- 16** – Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates
- **ASTM D3039/D3039M- 17** – Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials
- **ASTM D3171- 15** – Standard Test Methods for Constituent Content of Composite Materials
- **ASTM D3518/D3518M- 18** – Standard Test Method for In-Plane Shear Response of Polymer Matrix Composite Materials by Tensile Test of a ±45° Laminate
- **ASTM D3418-15** - Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry (DSC)
- **ASTM D5766/D5766M-11(2018)** – Standard Test Method for Open Hole Tensile Strength of Polymer Matrix Composite Laminates
- **ASTM D5961/D5961M-17** – Standard Test Method for Bearing Response of Polymer Matrix Composite Laminates
- **ASTM D6641/D6641M- 16e1** – Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials Using a Combined Loading Compression (CLC) Test Fixture
- **ASTM D6742/D6742M-17** – Standard Practice for Filled-Hole Tension and Compression Testing of Polymer Matrix Composite Laminates
- **ASTM E831- 19** – Standard Test Method for Linear Thermal Expansion of Solid Materials by Thermomechanical Analysis
- **ASTM D7028-07(2015)** – Standard Test Method for Glass Transition Temperature (DMA Tg) of Polymer Matrix Composites by Dynamic Mechanical Analysis (DMA)
- **ASTM E831- 19** – Standard Test Method for Linear Thermal Expansion of Solid Materials by Thermomechanical Analysis
- **FAR 25.853 (A), Appendix F, Part I, (a), 1, (i): 60 sec** – Burn length and Extinguishing time
- **FAR 25.853 (D), Appendix F, Part IV** – Drip Time and Heat Release Rate
- **FAR 25.853 (D), Appendix F, Part V** – Smoke Emission Characteristics

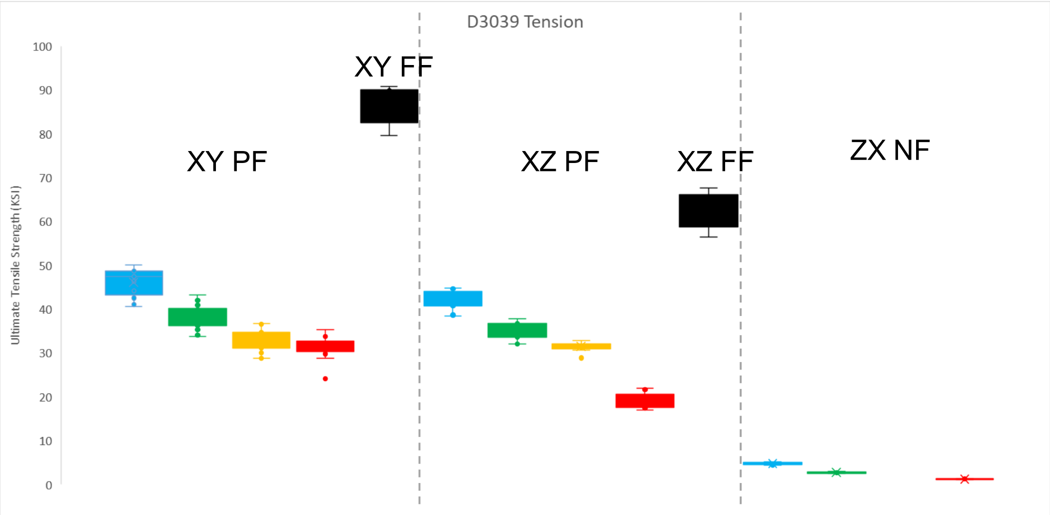
Mechanical Properties: Tension D3039

XY PF



XZ PF

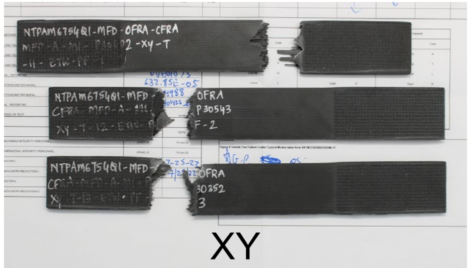




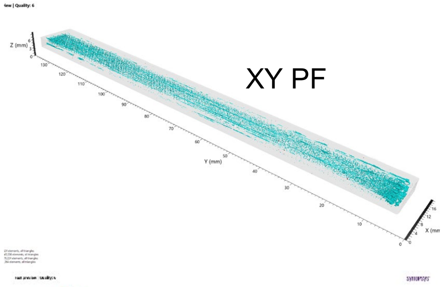
*ZX originally defined as PF; changed to NF

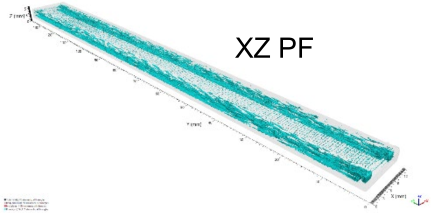
Elevated Temp: 130°F

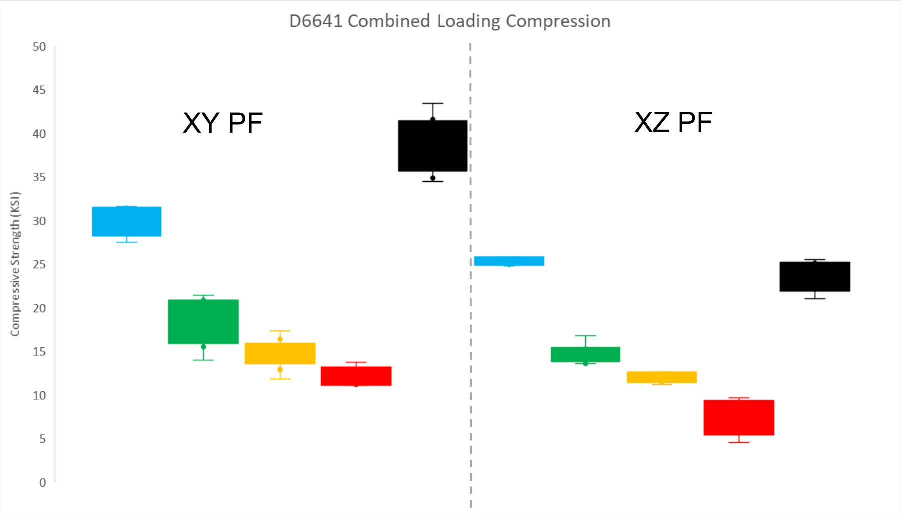
ASTM D3039		PF				FF
	Ultimate Tensile Strength (KSI)	CTD	RTD	ETD	ETW	FF RTD
XY	Mean	46.152	38.185	32.974	31.420	85.799
	CV	6.358	7.006	7.614	8.057	4.850
	Total pcs	19	19	15	16	6
	Percent Complete	100%	100%	83%	89%	100%
XZ	Mean	42.062	35.370	31.517	19.176	63.275
	CV	4.928	5.106	3.691	9.031	6.790
	Total pcs	17	18	9	10	6
	Percent Complete	94%	100%	50%	56%	100%
		NF				
ZX	Mean	4.797	2.754		1.251	
	CV	5.903	6.198		2.421	
	Total pcs	9	6		3	
	Percent Complete	50%	33%		17%	



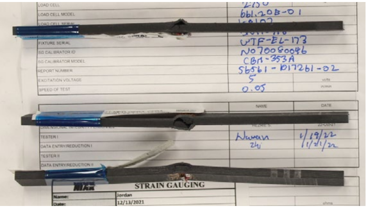
Mechanical Properties: Compression D6641

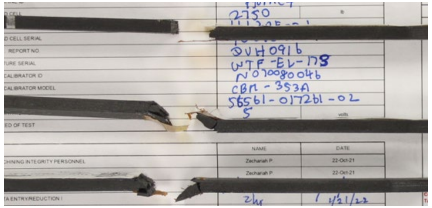

XY PF


XZ PF



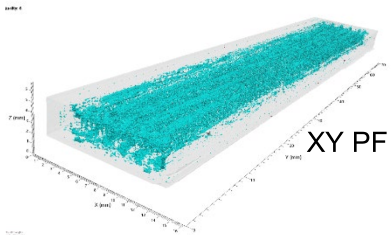
ASTM D6641		PF				FF
	Compressive Strength (KSI)	**CTD**	**RTD**	**ETD**	**ETW**	**FF RTD**
XY	Mean	29.856	18.362	14.663	11.859	39.118
	CV	5.443	13.807	11.449	10.547	8.067
	Total pcs	6	10	9	4	8
	Percent Complete	33%	56%	50%	22%	100%
XZ	Mean	25.198	14.620	11.980	7.648	23.477
	CV	2.028	6.720	5.041	28.685	7.192
	Total pcs	3	12	6	4	6
	Percent Complete	17%	67%	33%	22%	100%


XY PF


XZ PF

*Data for ZX NF Specimens by end of April

Mechanical Properties: Flex D790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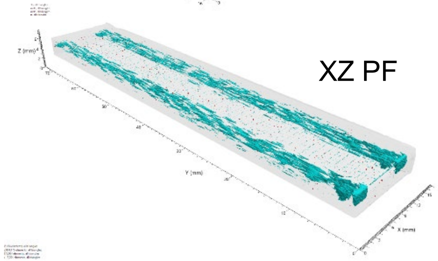
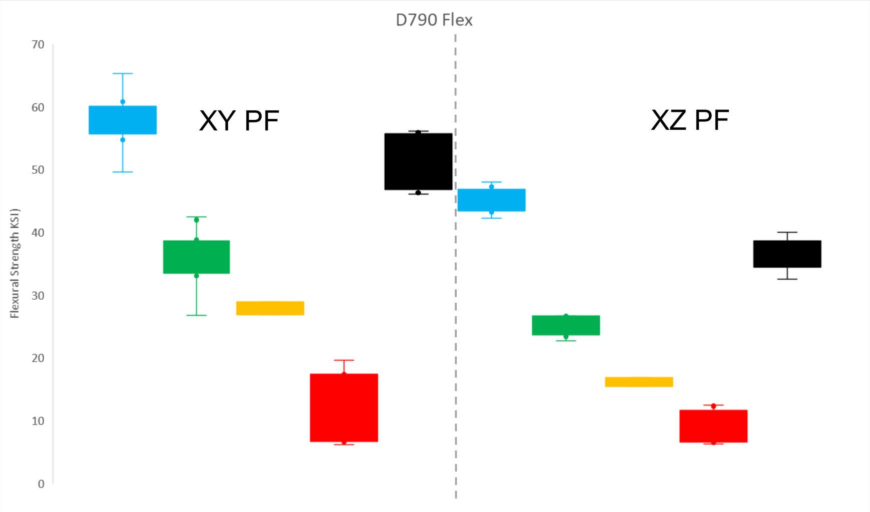
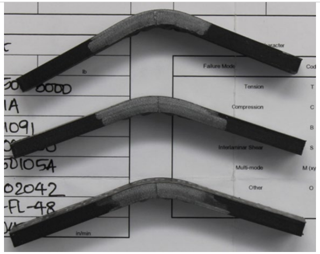
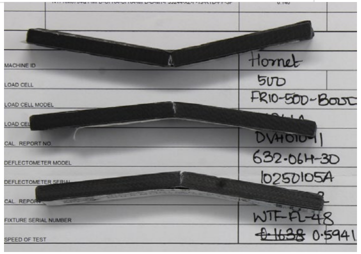

XZ PF



ASTM D790		PF				FF
	Flexural Strength (KSI)	**CTD**	**RTD**	**ETD**	**ETW**	**FF RTD**
XY	Mean	57.800	36.271	27.711	12.468	51.779
	CV	7.397	11.690	3.954	37.631	8.283
	Total pcs	9	12	3	11	8
	Percent Complete	50%	67%	17%	61%	100%
XZ	Mean	44.842	25.050	16.284	9.716	36.575
	CV	4.349	6.186	4.326	25.698	7.328
	Total pcs	9	9	3	9	6
	Percent Complete	50%	50%	17%	50%	100%


XY PF



XZ PF

*Data for ZX NF Specimens by mid April

Powder Bed Fusion Qualification - Filled Thermoplastic

Hexcel AM – PEKK + Carbon Fiber

Background

- **Motivation and Key Issues**
  - Expand on the qualification framework established through the ULTEM qualification program with a new process (polymer laser powder bed fusion)
  - Incorporate additional considerations for new process that also includes filled polymer material
  - Investigate equivalency approach for recycled material
- **Objective and Scope**
  - Collaborate with SMEs through a steering committee to conduct pre-qualification research to inform a robust qualification plan
  - Conduct a full qualification based on industry input
  - Generate property database and specifications
  - Transfer lessons learned to CMH-17
- **Approach**
  - Select a non-metallic AM material of interest that is process stable → HexAM
  - Previous data from America Makes program can be leveraged (no public specs generated and only available to America Makes members)
  - Engage industry SMEs throughout the process

Project Timeline

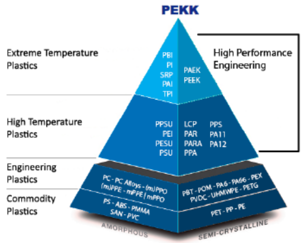
- All testing, data reduction, and reporting are expected to be completed in October of 2023
- DMA and flammability testing have been completed
- Ambient testing in process
- ETW and fluid sensitivity conditioning in progress

Q3 2022	Q4 2022	Q1 2023	Q2 2023	Q3 2023	Q3-Q4 2023
Final prints received from Hexcel	Database Processing, Machining, conformity	**- Testing Ambient coupons** **-ETW and fluid sensitive conditioning** **-DMA and flammability testing**	- Ambient data reviewing - Investigate into any issues that occurred	-Elevated wet testing - Fluid sensitive testing	-Data compilation -Statistics and material data report

HexAM Details

HexPEKK™

Polyetherketoneketone (PEKK)
- High performance thermoplastic
- Qualified from -300F to +300F
- FAR 25 (flammability) compliant



+

Carbon Fiber
- Carbon fiber added to PEKK at the powder stage
- Results in a composite with industry leading mechanical properties
- Meets ESD requirements

EXCLUSIVE-Boeing's space taxis to use more than 600 3D-printed parts

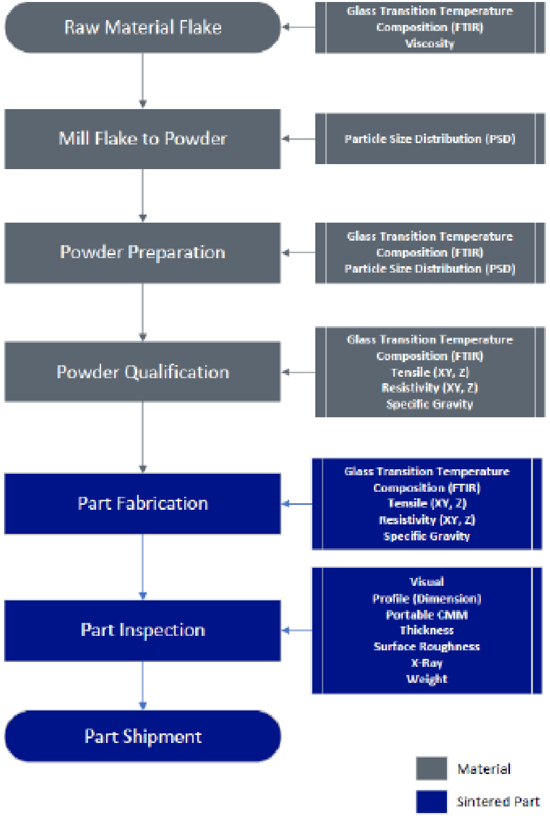
REUTERS

Applications:
- Commercial Aircraft – optimized brackets, ducts, castings
- Manned Space
- Satellite
- Military Aircraft

- **Parts are excavated out of unsintered powder material (“cake”)**
- **HexAM™ process allows the cake to be reclaimed, processed and run just like first use (“virgin”) powder**
  - Equivalency for cake and additional machines (Hexcel has 8)
- **No heat treat or support structure removal required**
- **Flightworthy hardware straight out of the machine**

Processing Information

Wichita State University
National Institute for Aviation Research



Raw Material Flake
- Glass Transition Temperature
- Composition (FTIR)
- Viscosity

Mill Flake to Powder
- Particle Size Distribution (PSD)

Powder Preparation
- Glass Transition Temperature
- Composition (FTIR)
- Particle Size Distribution (PSD)

Powder Qualification
- Glass Transition Temperature
- Composition (FTIR)
- Tensile (XY, Z)
- Resistivity (XY, Z)
- Specific Gravity

Part Fabrication
- Glass Transition Temperature
- Composition (FTIR)
- Tensile (XY, Z)
- Resistivity (XY, Z)
- Specific Gravity

Part Inspection
- Visual
- Profile (Dimension)
- Portable CMM
- Thickness
- Surface Roughness
- X-Ray
- Weight

Part Shipment

■ Material
🟦 Sintered Part

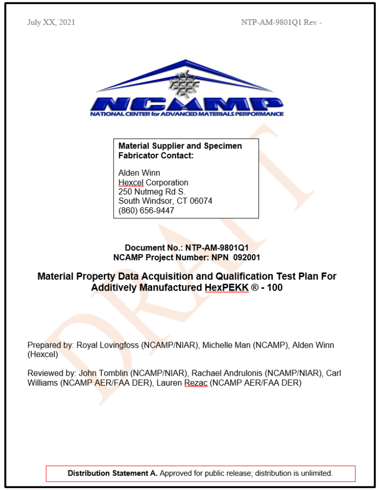
HexPEKK 100

PEKK Flake

PEKK Neat Powder

PEKK with Carbon Fiber

Documentation: Test Plan



July XX, 2021 NTP-AM-9801Q1 Rev -

NCAMP
NATIONAL CENTER for ADVANCED MATERIALS PERFORMANCE

Material Supplier and Specimen Fabricator Contact:

Alden Winn
Hexcel Corporation
250 Nutmeg Rd S.
South Windsor, CT 06074
(860) 656-9447

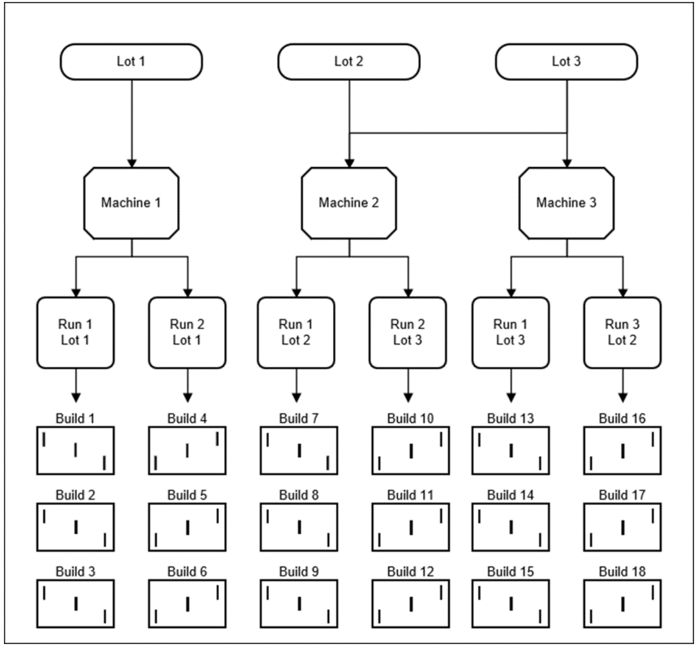
Document No.: NTP-AM-9801Q1
NCAMP Project Number: NPN 092001

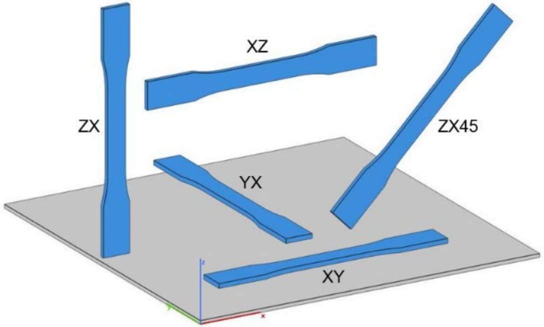
Material Property Data Acquisition and Qualification Test Plan For Additively Manufactured HexPEKK ® - 100

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

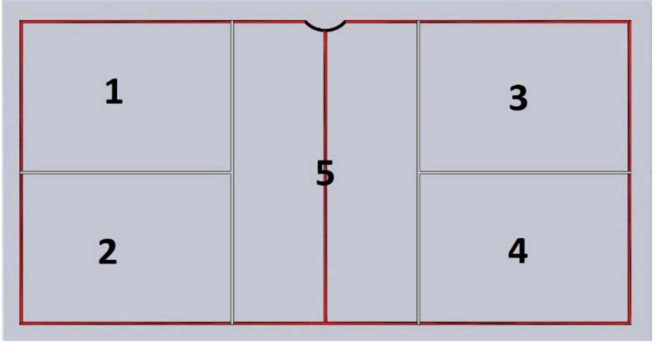
Reviewed by: John Tomblin (NCAMP/NIAR), Rachael Andrulonis (NCAMP/NIAR), Carl Williams (NCAMP AER/FAA DER), Lauren Rezac (NCAMP AER/FAA DER)

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





Build Orientation Investigation



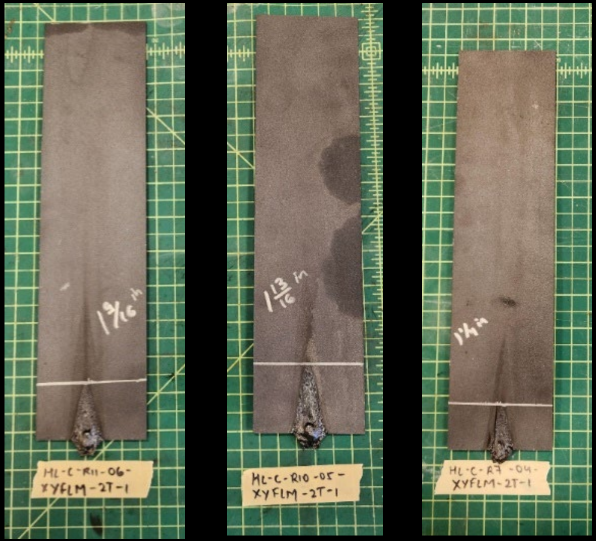
Build Location Investigation

FST testing results

Smoke Release: Pass

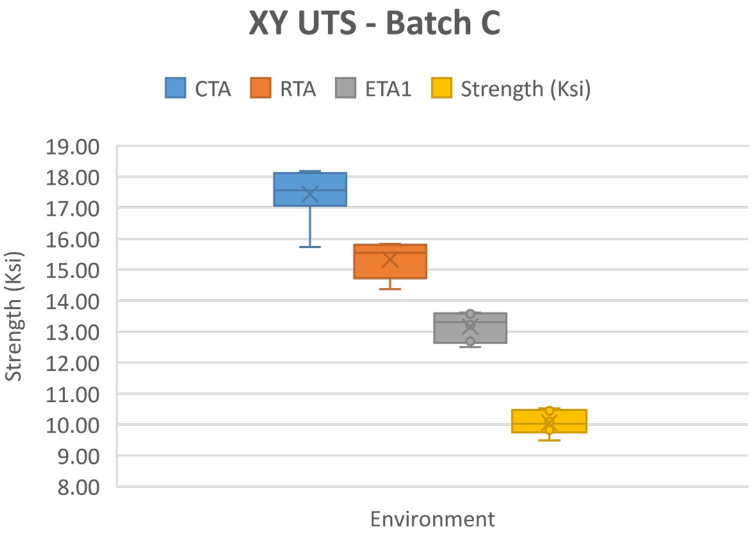
Heat Release: Pass

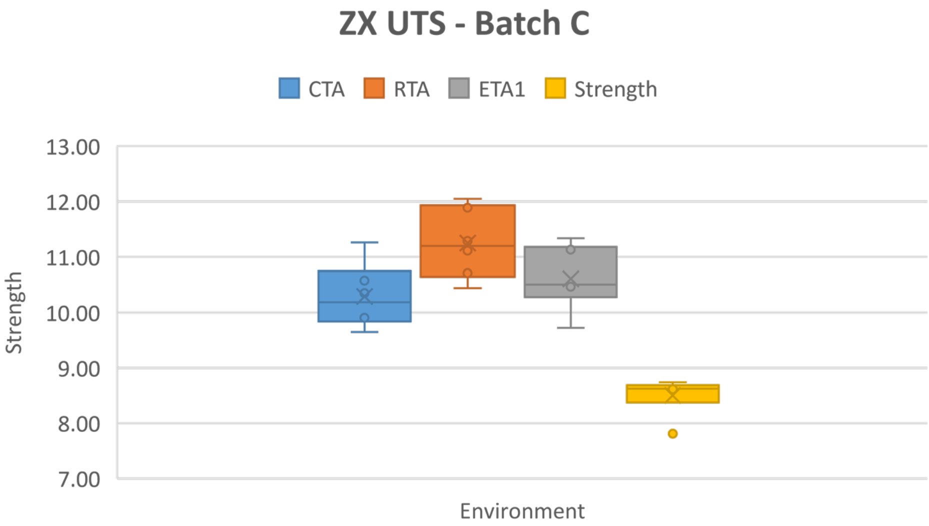
Vertical Flame: Pass



Qual: Tension Results

Preliminary data: n=6 per batch and condition


XY UTS - Batch C

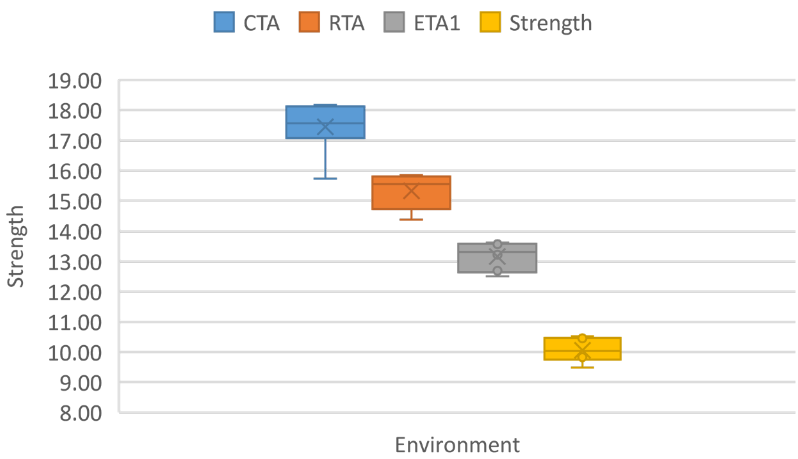

ZX UTS - Batch C

ETA1: 180°F   ETA2: 250°F

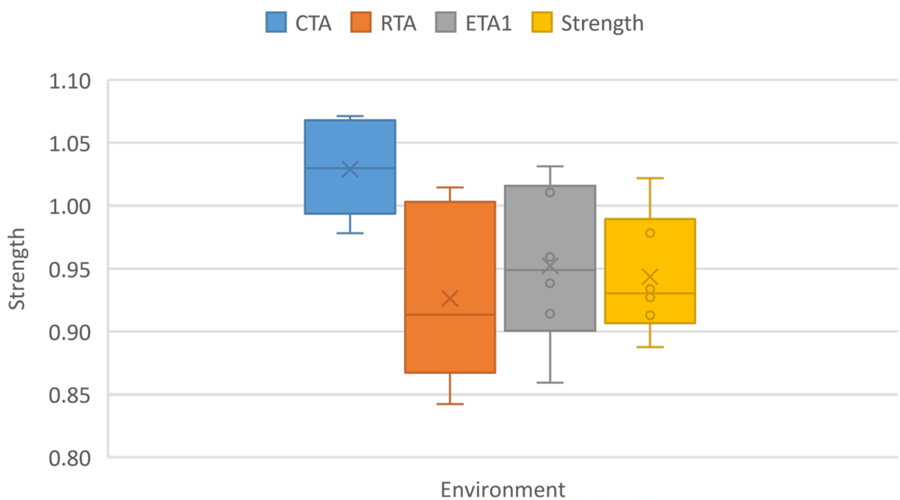
Qual: Compression Results


Tested Compression Cube

XY UCS Strength - Batch C



XY Compressive Modulus - Batch C



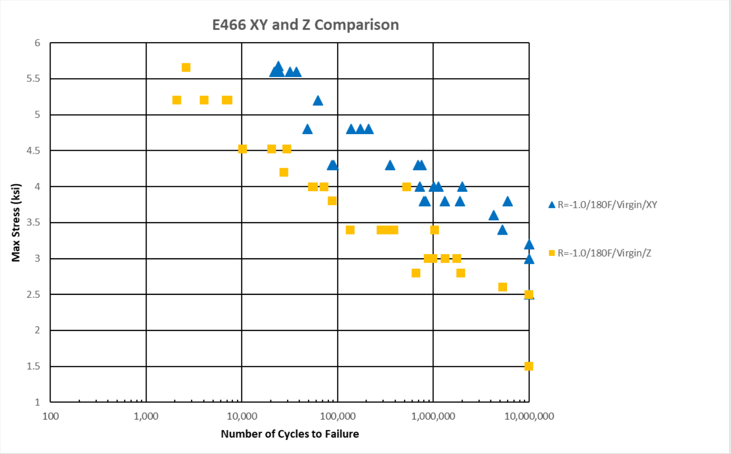
ETA1: 180°F   ETA2: 250°F

HexPEKK Fatigue Testing

- **Fatigue Testing on HexAM material being performed**
  - Can be published in CMH-17 along with qualification data

Status:

- **Trial Coupons tested (static and fatigue)**
  - All gage failures
  - Some alignment and roundness issues
  - Processing changes to achieve better alignment
- **Test Plan**
  - Input from Steering Committee



Antero 800 and 840 Qualifications

- Manufactured by Stratasys
- Replacement materials for Ultem 9085
- Antero 800 – neat PEKK polymer
- Antero 840CN03 - short-fiber (CF) reinforced PEKK polymer
- Additively Manufactured using FFF/MEX process
- Increased material strength and modulus properties compared to Ultem 9085
- Designed to print on the F900, newest Stratasys MEX machine

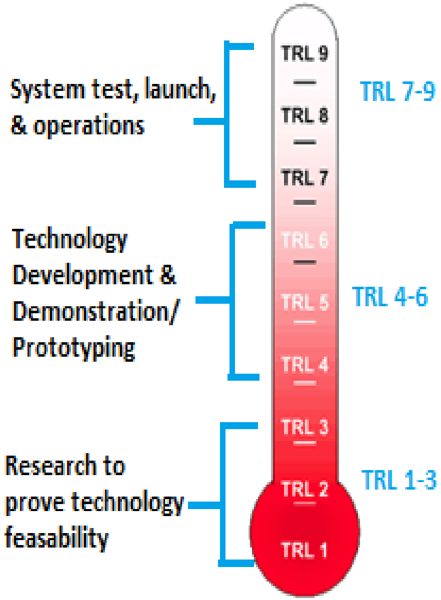
Antero
Schedule and Deliverables

- **Timeline: May 15, 2023 to May 31, 2024**
  - Trials: June 2023 to August 2023
  - Monthly meetings will be held after steering committee is established
  - Qualification: end May 31,2024

- **Deliverables:**
  - Trial study data
  - NCAMP reports and specs
  - Final report documenting lessons learned

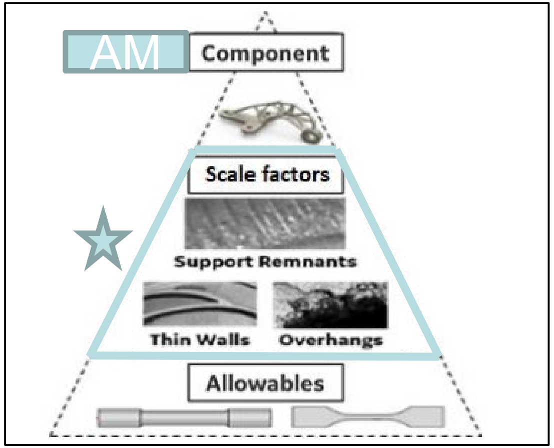
Roadmap Study

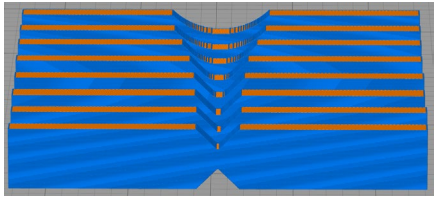
- **Objective**
  - This study is intended as a guide to capture current material and machine capabilities to inform the FAA for awareness and definition of further research studies.
  - Develop a living document that surveys the state of the industry on additive manufacturing techniques, technologies, and materials in terms of TRL level.
- **Status**
  - The final report submitted for FAA review Dec 2022.
  - Report will be updated yearly for current snapshot of state of the industry.



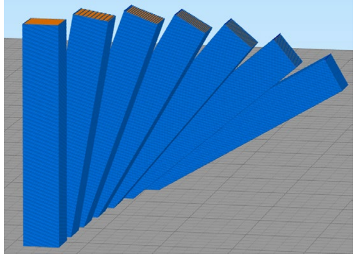
Building Block Study

- **Objective**
  - To generate qualifying criteria for manufacturing and repair houses in order for the FAA to certify an organizations' ability to fabricate parts using AM.
  - Qualifying Criteria of Interest:
    - Design Feature Type
      - Thin Walls
      - Overhangs
      - Radii
      - Lattice Structures
      - Holes
    - Geometry
    - Fabrication Methodology
  - To progress any AMSC Roadmap gaps utilizing work performed in the project.
- **Status**
  - Steering Committee established August 2021.
    - Kick-off meeting held on August 25th, 2021.
    - Steering committee meeting scheduled for April 29th, 2022 to verify feature type investigation designs along with the use cases for each fabrication methodology.
  - Designs and preliminary inspection methods for each feature type have been developed.

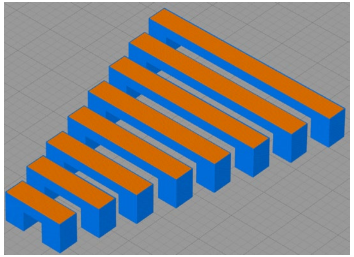




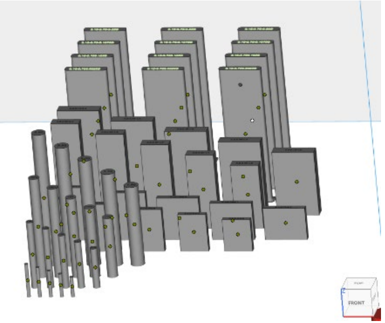
Polymer FFF to investigate radii fabrication quality (capability) and mechanical performance



Polymer FFF to investigate overhangs for both fabrication quality (capability) and mechanical performance



Polymer FFF to investigate bridging for both fabrication quality (capability) and mechanical performance



Metallic L-PBF build to investigate thin walls and holes for both quality (capability) and mechanical performance

Research Studies/ Factors Affecting Qualification

Effects of Key Parameter Adjustment on Microstructure and Tensile Strength – Structure Property Mapping

- Final report submitted to FAA Dec 2022.

Machining Effects on Tensile Properties of Additively Manufactured ULTEM 9085 CG Specimens

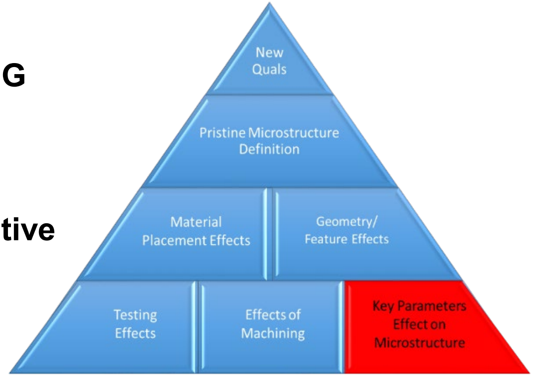
- Final report submitted to FAA April 2023.

Raster Angle and Specimen Thickness Effects on Mechanical Performance of Additive Manufactured ULTEM 9085™ MEX

- Final report submitted to FAA April 2023.

Parameter and geometric effects on FST properties

- Assess the effect of select processing parameters (such as density, build strategy, insight parameters) on the final FST (flammability, smoke, toxicity) properties for the existing ULTEM 9085 database. Report under final NIAR review.



Post-ULTEM Qualification Guideline Development

- **Status**
  - ASTM WK66029 Guidance document went through ballot
    - Standard Guide for Additive Manufacturing of Polymers—Material Extrusion—Recommendation for Material Handling & Evaluation of Static Mechanical Properties
    - Addressing single negative vote
  - ASTM WK71391 Alternative AM Test Geometries Guide in work
  - Supported development of SAE AMS-AM for ULTEM specifications
  - On-going support of ASTM F42, D20, and ASTM AM COE
  - CMH-17 AM Volume created with working groups established

- **Deliverables**
  - AMS 7100 & AMS 7101 Published
  - ASTM work item F42.01 WK71391 in process for alternative geometries for tension & compression
  - ASTM WK66029 ballot – negative vote removed 4/17/23

Looking Forward

- **Benefits to Aviation**
  - Allows adoption of AM processes and materials within the aviation industry
  - Provides enabling allowables data for actual part design and manufacture
  - Creates guidance and specification documents to facilitate adoption
- **Future Needs:**
  - Demonstrate scalability of AM qualification framework to increasingly complex material and process types
  - Demonstrate equivalency method to additional machines within material and process type
  - Provide data enabling research up the building block pyramid
- **Contact:**
  - Rachael Andrulonis (Rachael.Andrulonis@idp.Wichita.edu)
  - Joel White (Joel.White@idp.Wichita.edu)

Publications

Publication Type	Date	Publication
NCAMP Documents	Jan-21	“NCAMP Material Specification for ULTEM 9085 Resin,” NMS 085 Rev C, January 15, 2021.
NCAMP Documents	Apr-21	“NCAMP Process Specification for Polymer Additive Manufacturing Materials, Machine, Processing, and Quality Requirements Specification for ULTEM 9085 and Stratasys Fortus 900mc Machine,” NPS 89085 Rev D, April 18, 2021.
Conference Presentation	Nov-21	R. Lovingfoss, Polymer Additive Manufacturing Research Programs at WSU-NIAR, ASTM International ICAM Conference, November 2021.
Conference Presentation	Nov-21	Presentation - JAMS AM Research Overview, presented to CMH-17 AM Committee, November 2021.
FAA Technical Reports	Dec-21	FAA Annual Report, “Additive Manufacturing Guidance for Aircraft Design and Certification,” December 2021 (submitted).
Test Method	Mar-22	Balloted Item - ASTM Work Item WK66029/WK71391– New Guide for Mechanical Testing of Polymer Additively Manufactured Materials
Tutorial	Mar-22	ASTM AM CoE Additive Manufacturing General Personnel Certificate Course: Presentations on mechanical test methods resulting from ULTEM Qual and Statistical Methodologies
Conference Presentation	Apr-22	Presentation - JAMS AM Research Overview, presented to CMH-17 AM and SAE Committees, April 2022
Conference Presentation	Sep-22	NAVSEA 05T’s Polymers in Marine Environments Workshop, titled “ULTEM 9085cg Qual and Additively Manufactured Polymer Test Coupons”.
Conference Presentation	Nov-22	Presentation for ASTM ICAM Tuesday, November 1st, 2022, PBAM Activities at NIAR
FAA Technical Report	Dec-22	Qualification of Additively Manufactured Material Extrusion Thermoplastic and Lessons Learned
FAA Technical Report	Dec-22	ULTEM 9085™ Material Extrusion Polymer Based Additive Manufacturing: Process Parameter Effects on Mechanical Performance
FAA Technical Report	Dec-22	Guidelines and Recommended Criteria for the Development of a Material Specification for Extrusion Based Additively Manufactured Polymer Materials
Conference Presentation	Apr-23	NIAR ASTM Project Updates, ASTM D20.10.42 Meeting, April 11, 2023 (Virtual Meeting)

Questions?

Thank you

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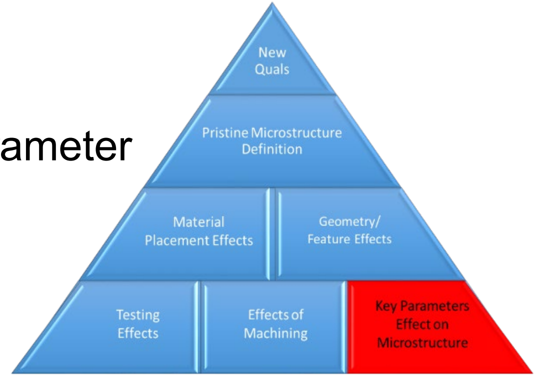
Backup slides

Structure Property Mapping

- **Objective**
  - Theory: consistent microstructure will allow for different machines to achieve the same mechanical performance.
  - First step in determining possibility of expanding machines and platforms.
  - Process parameters and input variables were tightly controlled and limited during the U9085 qualification but need to be correlated back to a micro-structure definition to prove that a range of operating conditions could be available on the F900/900mc.
- **Overview**
  - Literature review completed on weight of influence by parameter
  - Test & Fab Matrix and Test Plan: vary 8 HIGH to MED impact variables
  - 720 Specimens printed and tested – D638 tensile
  - **Final report submitted to FAA Dec 2022.**



New Quals

Pristine Microstructure Definition

Material Placement Effects

Geometry/ Feature Effects

Testing Effects

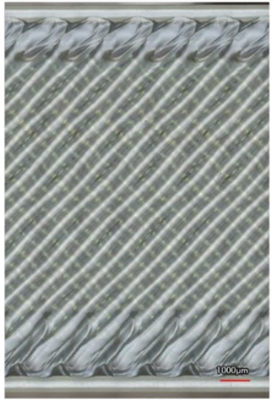
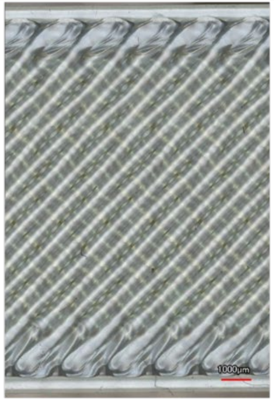
Effects of Machining

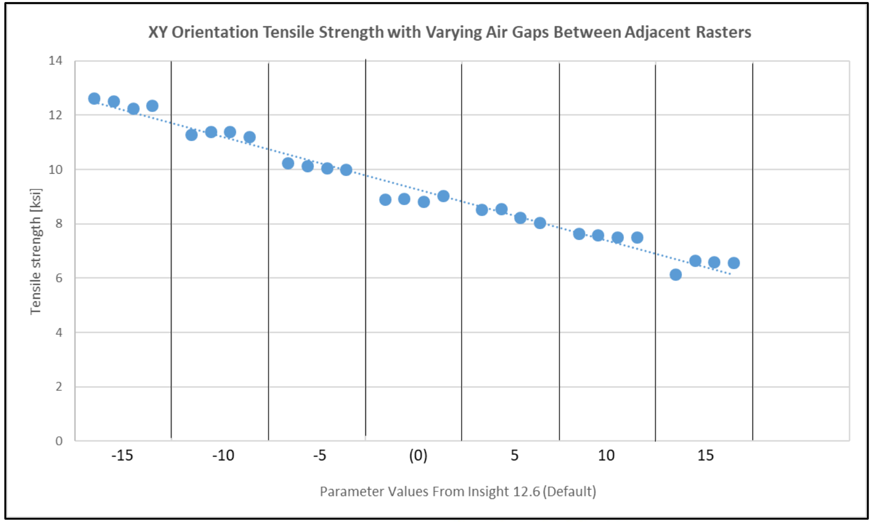
Key Parameters Effect on Microstructure

Structure Property Mapping: Select Results

- Air gap settings (adjacent rasters, contour and rasters, and contour to contour) were the only parameters that showed significant trends
- Parameter changes decreased tensile performance without effect to CoV

Air Gaps Between Adjacent Rasters
XY orientation results

-0.0015 inch Overlap	Baseline (0 inch – no gap)	0.0015 inch gap
		
Average Tensile Strength (ksi)		
12.44	8.92	6.49



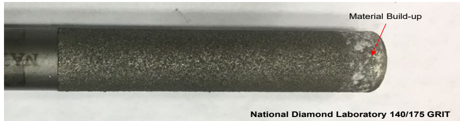
Machining Studies

- **Objective**
  - Determine methods of machining/grinding/finishing that do not introduce surface defects and flaws altering the behavior of the material and determine if the micro-structure can be upheld after machining.
- **Overview**
  - Best practices and literature review on machining FFF completed
  - Three machine techniques explored with 1 and 2 contours fabricated
  - Printing and Testing completed; key results on next slide
- **Final report submitted for FAA review Dec 2022.**

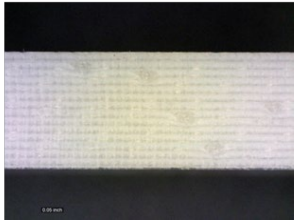
Machining Study Results

2000 rpm
30 inch per minute
SURFACE ROUGHNESS : ≥32 Micro

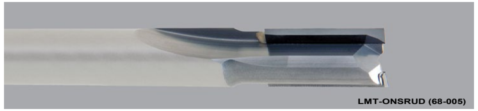
Grinding Mandrel:



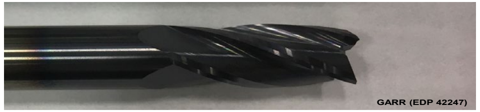
DIAMOND TOOL 140/175 GRIT
SURFACE ROUGHNESS : ≥32 Micro



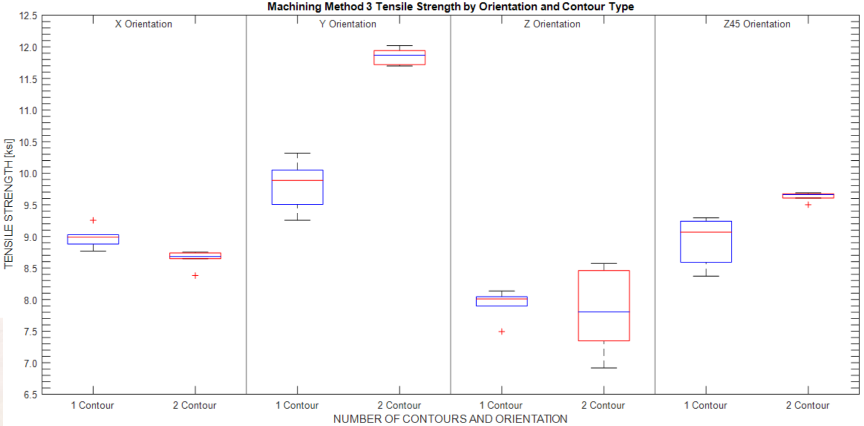
Finishing End Mill:

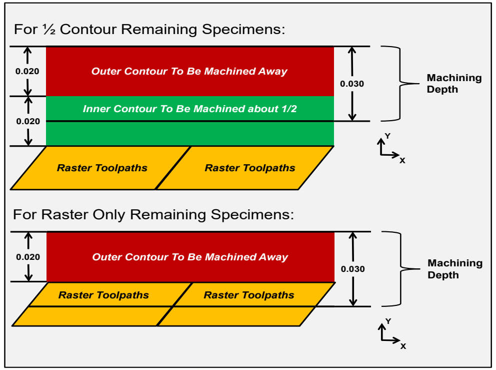


Roughing End Mill:



7500 rpm @ 50 inch per minute
SURFACE ROUGHNESS : ≥32 Micro





For ½ Contour Remaining Specimens:

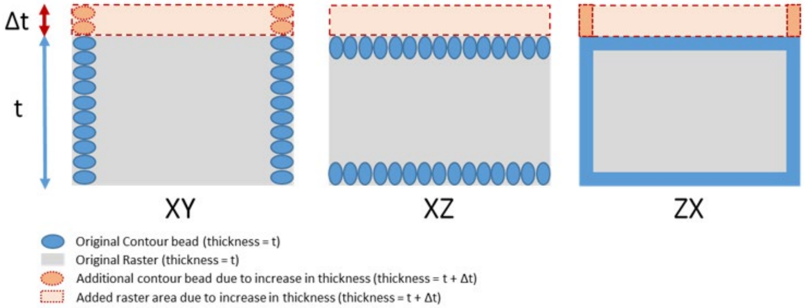
For Raster Only Remaining Specimens:

Specimen Scaling Studies

- **Objective**
  - Perform building block analysis for initial feature-level testing.
  - This study addressed how initial raster angle, specimen thickness, and contour thickness impacts tensile strength.
- **Overview**
  - 108 specimens fabricated at three different cross-sectional areas (ASTM D638)
  - Gage widths of 0.5” and 0.75” for Type 1 and Type 3 specimens (XY only)
  - Two thicknesses (0.13” and 0.28”), Type 3 0.300” thick
  - As-fabricated and contour removed by machining
  - Initial raster angle varied from 0° to 40°
  - ***An increase in gage width for XY specimens leads to decrease in tensile strength (all else held constant)***
  - ***As-machined tensile strength reduced compared to as-fab***
- **Final report submitted for FAA review April 2023.**

Effects of specimen scaling and machining
Project Details & Results

- This study intended to determine the effect of varying specimen thickness, five D638 geometries, and two finish types on UTS.
- The results showed that UTS was lower for thicker XZ specimens as thinner coupons have a higher percentage of contours on a given cross-section area within a gauge section.
- For as-fabricated specimen tensile testing the use of Type 1 geometry is recommend based on the low dispersion in data.
- The use of Type 3 geometry is recommended for as-machined coupon testing as Type 3 has the largest dimensions which allow the machine shop to fix the coupon position on a machine resulting in more accurate machining and an increase in surface quality.
- In an application where both surface quality and consistent tensile strength are required, the use of Type 4 and DF are not recommended due to the small dimensions.



Comparison of a cross-section area diagrams in a gauge section and effect of increased thickness in XY, XZ, and ZX

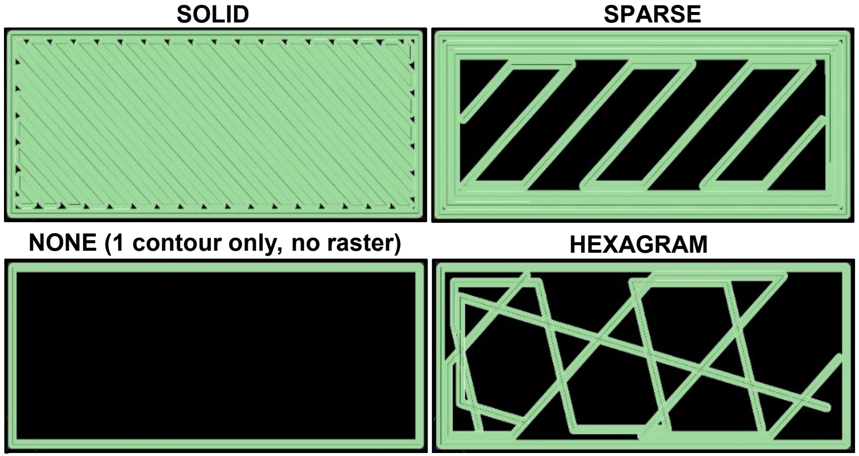
Pre-test and post-test specimens

FST: Project Details & Results

- **Objective:** To assess select processing parameters (such as density, build strategy, insight parameters) on the final FST (fire, smoke, toxicity) properties for the existing ULTEM 9085 database.

- This study intended to determine the effect of varying specimen thickness and infill pattern on flammability and to develop an understanding of worst-case FST properties due to a possible fabrication failure or worst-case designs for FST in additively manufactured thermoplastic interiors.

- ***No combination of thin walled structures, high air to part volume, infill, or parameter settings were able to create a failing ULTEM 9085 FST failing environment.***
- Final report submitted for FAA review Dec 2022.



Infill style used in builds

Pre (left) and post-test (right) vertical burn test specimens