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ULTEM 9085 Post Qualification Activities

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Joint Centers of Excellence for Advanced Materials

Federal Aviation Administration

CECAM
center of excellence for composites and advanced materials

FAA JAMS – Polymer AM | Program Overview

P-U9085	ULTEM 9085 Follow-On Activities	• Material Extrusion Guidelines • ULTEM Statistical Equivalency • ASTM Test Standards Development • Other Reports
P-MONYX	Markforged Qualification	Material qualification for Markforged's Additively Manufactured Polymer Composite Material Onyx FR-A (OFRA) reinforced with continuous Carbon Fiber FR-A (CFRA).
P-HPEKK	HexPEKK Qualification	Expand on the qualification framework established through the ULTEM qualification program with a new process (polymer laser powder bed fusion).
P-AN8X0	Antero 800 & 840 Qualifications	Expand on the qualification framework established through the ULTEM qualification program with a new materials and updated machine architecture (F900).

Post ULTEM 9085 Qualification Activities

Project Overview

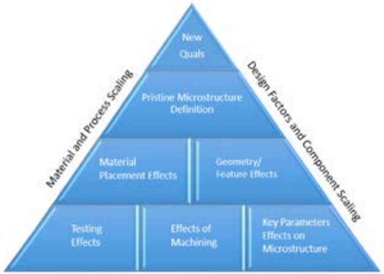
Research Objectives

- Leverage completed ULTEM 9085 qualification for additional research studies to facilitate the understanding and application of ULTEM.
- Complete statistical analysis on equivalency studies.
- Provide guidelines on best practices on developing material specifications for extrusion.
- Develop standards that document best practices on testing material extrusion specimens.

Accomplishments

Research Outcomes

- FAA Technical Reports documenting the factors affecting qualification.
- FAA Technical Report on ULTEM 9085 equivalency studies.
- FAA Technical Report on guidelines for a material specification (MEX).
- ASTM Test Standards on best practices and alternative geometries for PBAM materials.



Project Timeline – Outline of Deliverables

Date	Report Title
2022	Qualification of Additively Manufactured Material Extrusion Thermoplastic and Lessons Learned
2022	ULTEM 9085™ Material Extrusion Polymer Based Additive Manufacturing: Process Parameter Effects on Mechanical Performance
2022	Guidelines and Recommended Criteria for the Development of a Material Specification for Extrusion Based Additively Manufactured Polymer Materials – *Feedback Received (modifications needed)*
2023	Machining Effects on Tensile Properties of Additively Manufactured ULTEM 9085 CG Specimens
2023	Raster Angle & Specimen Thickness Effects on Mechanical Performance of Additive Manufactured ULTEM 9085™ MEX
2023	ASTM F3489-23: Standard Guide for Additive Manufacturing of Polymers — Material Extrusion — Recommendation for Material Handling and Evaluation of Static Mechanical Properties
2024	Test Method Modifications and Guides
2024	Parameter and Geometric Effects on FST properties
2024	ULTEM 9085 Equivalency Studies

Partners

Designation: F3489 – 23

Qualification and Lessons Learned


DOT/FAA/TC-xx/xx

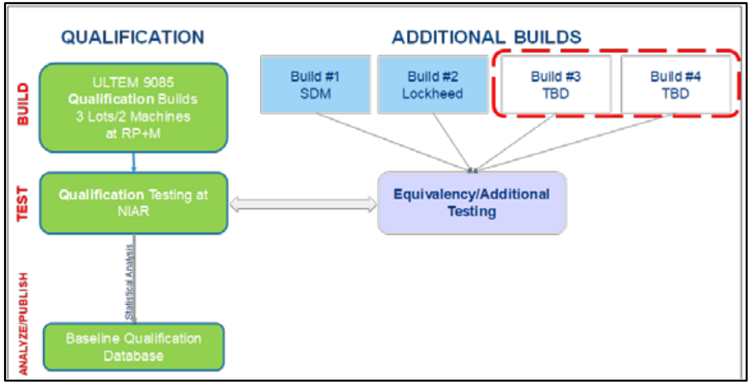
Federal Aviation Administration
William J. Hughes Technical Center
Aviation Research Division
Atlantic City International Airport
New Jersey 08405

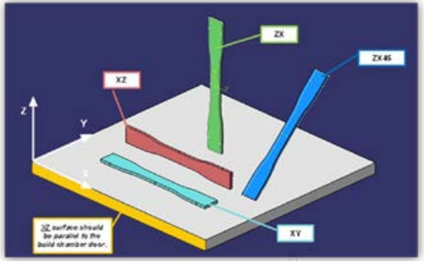
Qualification of Additively Manufactured Material Extrusion Thermoplastic and Lessons Learned

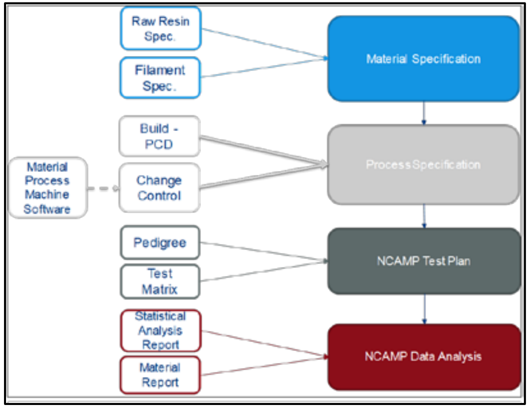
December 30, 2022

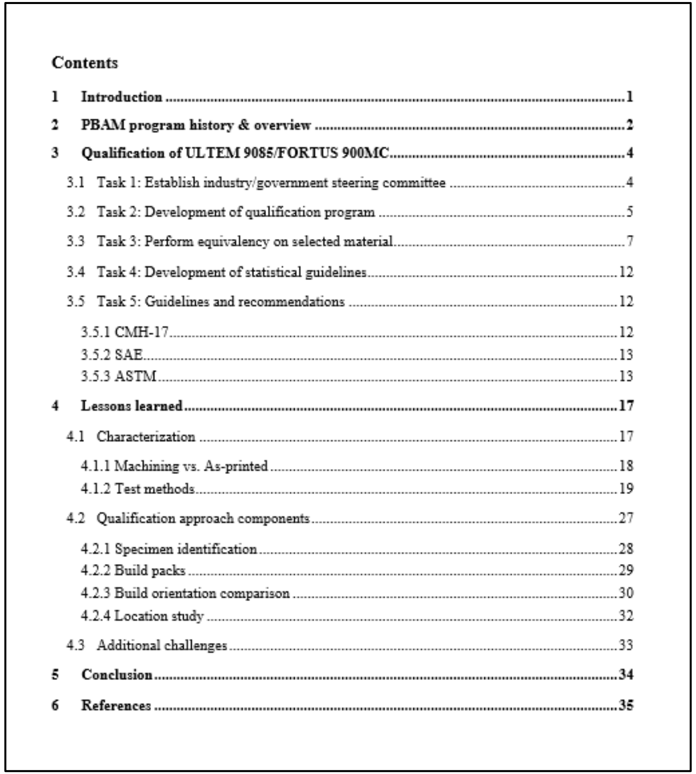
Final Report

U.S. Department of Transportation
Federal Aviation Administration








Contents

Guidelines and Recommended Criteria for the Development of a Material Specification for Extrusion Based Additively Manufactured Polymer Materials

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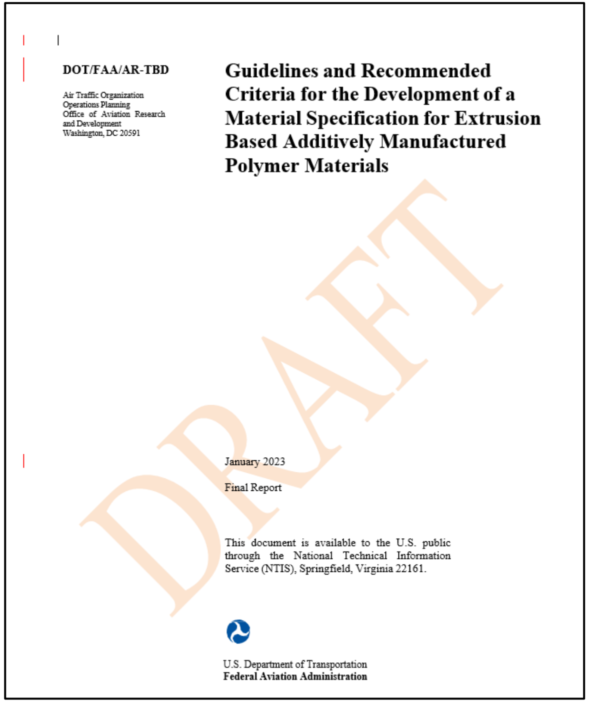
- Similar to DOT/FAA/AR-06/10 for PMCs.
- Provides **recommended guidelines and criteria for the development of material specifications** for extrusion based additively manufactured polymer materials to be used in the aircraft industry.
- This report is intended to be a companion to previous Federal Aviation Administration reports which established methodology for developing composite material allowable data, control of the data, and sharing the resulting database.
- The guidelines and recommendations are meant to be a **documentation of current knowledge and practices**, and application of sound engineering principles to the development and implementation of extrusion based additively manufactured **material procurement specifications**.
- A list of material control areas needing improvement and enhancement is provided for discussion. This document can also be used to **develop common industry specifications**.



DOT/FAA/AR-TBD

Air Traffic Organization
Operations Planning
Office of Aviation Research and Development
Washington, DC 20591

Guidelines and Recommended Criteria for the Development of a Material Specification for Extrusion Based Additively Manufactured Polymer Materials

DRAFT

January 2023

Final Report

This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161.

U.S. Department of Transportation
Federal Aviation Administration

INDUSTRIAL MODERNIZATION OF MATERIALS & MANUFACTURING

ASTM Test Methods, SAE Specs and CMH-17 Guidance

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- **ASTM F3489-23**: Standard Guide for Additive Manufacturing of Polymers — Material Extrusion — Recommendation for Material Handling and Evaluation of Static Mechanical Properties
- **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

Outputs

- AMS 7100 & AMS 7101 Published
- ASTM work item F42.01 WK71391 in process for alternative geometries for tension & compression

This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: F3489 – 23

Standard Guide for
Additive Manufacturing of Polymers — Material Extrusion — Recommendation for Material Handling and Evaluation of Static Mechanical Properties[1]

This standard is issued under the fixed designation F3489; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers existing standards or variations of existing standards that may be applicable to determine specific static mechanical properties of polymeric specimens fabricated with the material extrusion (MEX) additive manufacturing (AM) process. The test methods covered within this document are recommendations supplied coming from the experience previous material qualification programs have provided. Additional test methods may be considered as well depending when evaluating material performance for specific applications. Recommendations for material handling prior to testing and characterization are included as they can greatly affect material properties. It is for the end user to determine if the recommended tests adequately evaluate the material performance for the intended application.

1.2 *Units*—The values stated in SI units are to be regarded as the standard. No other units of measurement are included in this standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]
D638 Test Method for Tensile Properties of Plastics
D695 Test Method for Compressive Properties of Rigid Plastics
D790 Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
D3039 Test Method for Tensile Properties of Polymer Matrix Composite Materials
D5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
D5379 Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method
D5766 Test Method for Open-Hole Tensile Strength of Polymer Matrix Composite Laminates
D5961 Test Method for Bearing Response of Polymer Matrix Composite Laminates
D6484 Test Method for Open-Hole Compressive Strength of Polymer Matrix Composite Laminates
D6641 Test Method for Compressive Properties of Polymer Matrix Composite Materials Using a Combined Loading Compression (CLC) Test Fixture
D6742 Practice for Filled-Hole Tension and Compression Testing of Polymer Matrix Composite Laminates
D7191 Test Method for Determination of Moisture in Plastics by Relative Humidity Sensor
F2971 Practice for Reporting Data for Test Specimens Prepared by Additive Manufacturing

2.2 *ISO/ASTM Standards:*[2]
ISO/ASTM 52900 Additive manufacturing — General principles — Terminology
ISO/ASTM 52921 Standard terminology for additive manufacturing — Coordinate systems and test methodologies

[1] This guide is under the jurisdiction of ASTM Committee F42 on Additive Manufacturing Technologies and is the direct responsibility of Subcommittee F42.01 on Test Methods.
Current edition approved May 1, 2023. Published June 2023. DOI: 10.1520/F3489-23.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

IM3 INDUSTRIAL MODERNIZATION OF MATERIALS & MANUFACTURING

JAMS

Process Parameter Effects on Mechanical Performance

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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 high impact parameters
- 720 Specimens printed and tested – D638 tensile
- Final report submitted to FAA Dec 2022.

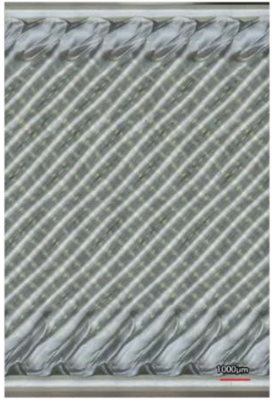
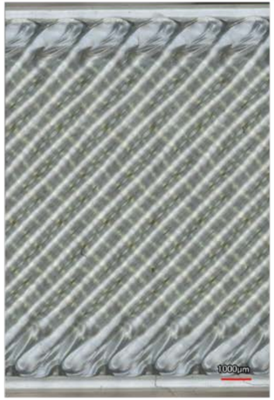
1. Number of Contours (NC)	4. Enhanced Visible Surface Raster Air Gap (EVSRAG)	7. Air Gaps Between Contours and Rasters (CR)
The number of contours built around all outer and inner curves.	The gap between adjacent visible surface raster toolpaths.	The gap between the innermost contour and the edge of the raster fill inside the contour.
2. Part Raster Width (PRW)	5. Surface Max Contour (SMC)	8. Air Gaps Between Contours—2 Contours (CC2)
The toolpath width of the raster pattern used to produce solid fill regions of part curves.	The toolpath automatically sets up surface max contours on visible rasters to hide raster turn-arounds when enhanced visible surface rasters are used.	The gap between contours when the part fill style is with two contours.
3. Enhanced Visible Surface Raster Width (EVSRW)	6. Air Gaps Between Adjacent Rasters (AR)	9. Air Gaps Between Contours—3 Contours (CC3)
The toolpath used to produce visible and internal raster widths.	The air gap between adjacent raster toolpaths.	The gap between contours when the part fill style is with three contours.

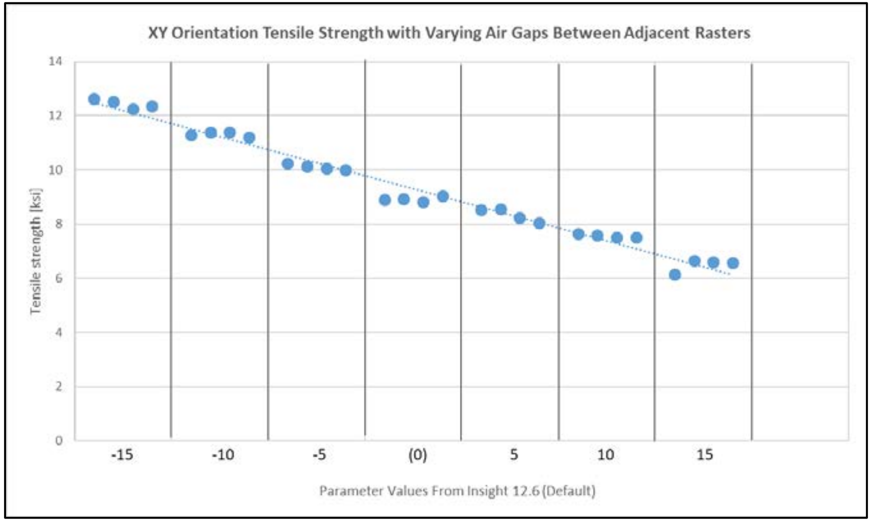
Figure 9. Definitions of each high impact insight parameter

- 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 coefficient of variation

<u>Air Gaps Between Adjacent Rasters</u>

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



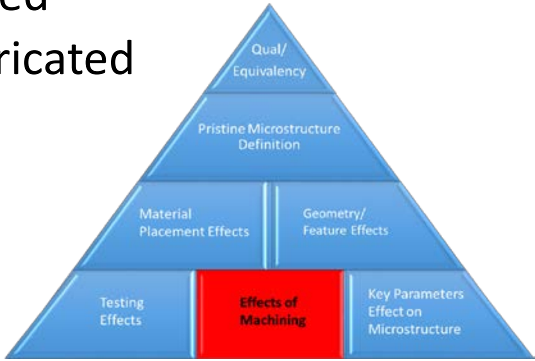
Machining Effects on Tensile Properties

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

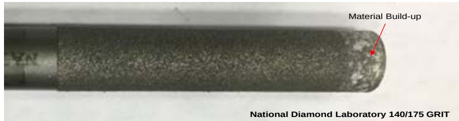
- Best practices and literature review on machining FFF completed
- Three machine techniques explored with 1 and 2 contours fabricated
- Printing and testing completed; key results on next slide
- Final report submitted for FAA review Dec 2022.



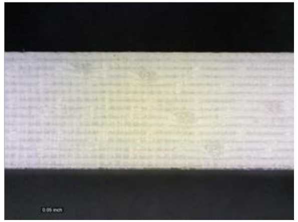
Machining Study Results

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

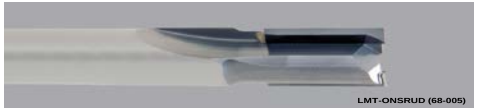
Grinding Mandrel:



- 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

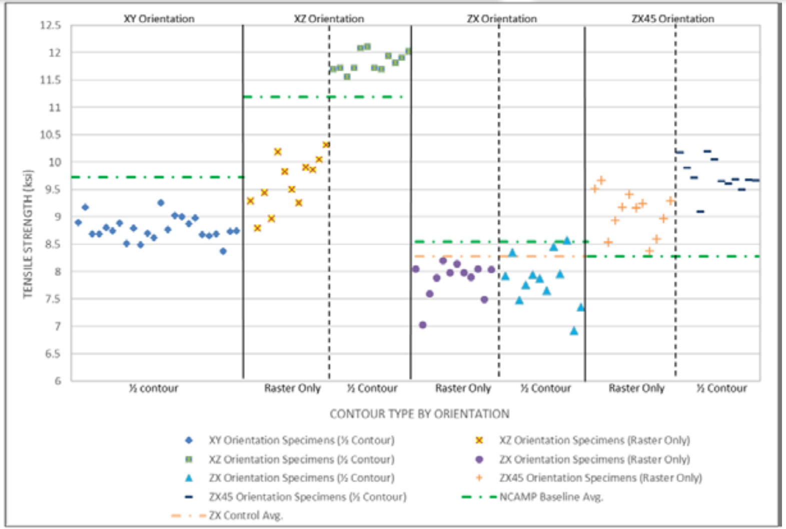
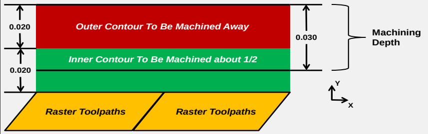
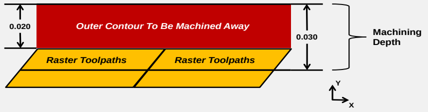


Figure 1. Machining method 3 tensile strength by orientation and contour type

For ½ Contour Remaining Specimens:



For Raster Only Remaining Specimens:



Raster Angle & Specimen Thickness Effects on Mechanical Performance

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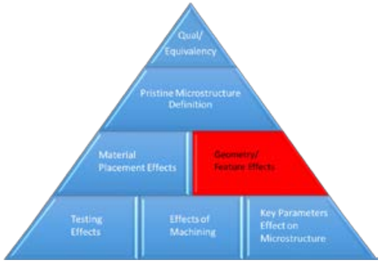
- **Objective**
  - Perform building block analysis for initial feature-level testing.
  - This study addressed how initial raster angle, specimen thickness, and contour thickness impacts tensile strength.
- **Overview**
  - 108 specimens fabricated at three different cross-sectional areas (ASTM D638)
  - 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.



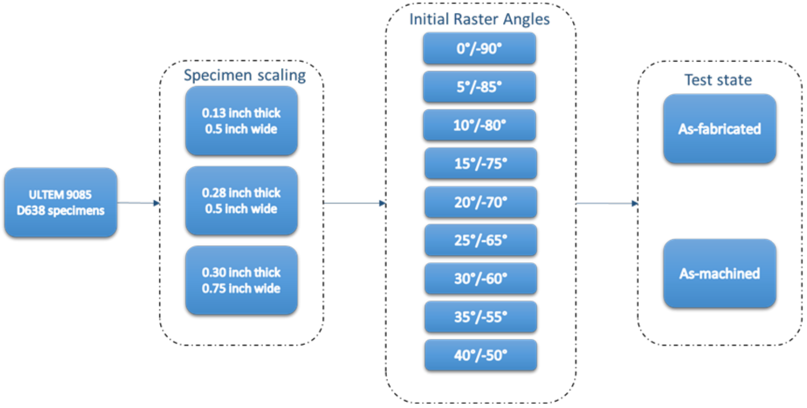
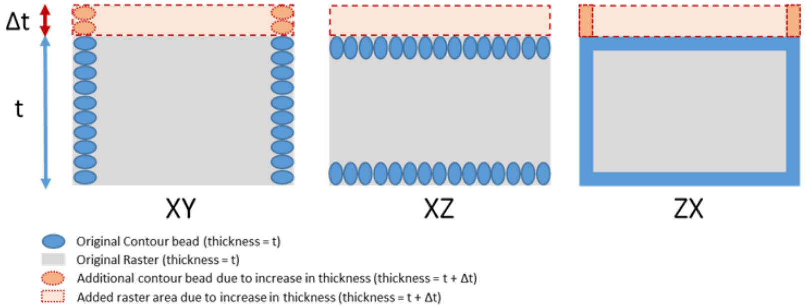


Figure 1. Project specimen flow

Effects of specimen scaling and machining

- This study examined the effects of varying specimen thickness, five D638 geometries, and two finish machining methods 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.



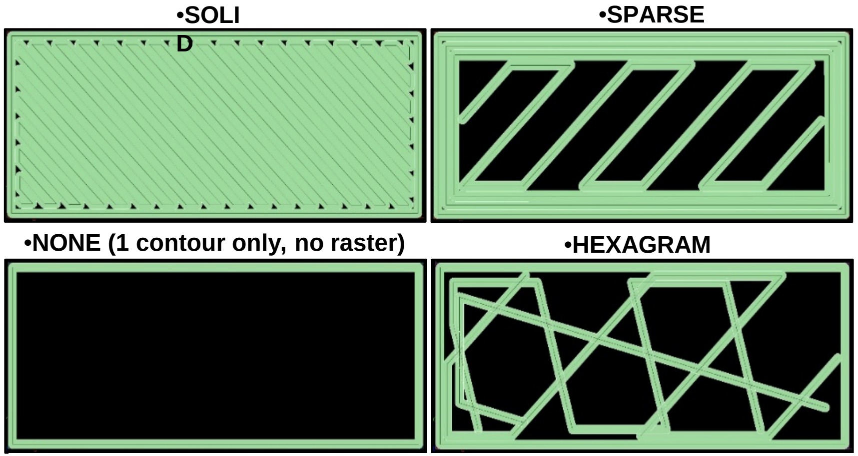
Comparison of a cross-section area diagrams in a gauge section and effect of increased thickness in XY, XZ, and ZX

Pre-test and post-test specimens

Parameter and Geometric Effects on FST properties

- **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.
- 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 prepared and ready to submit.

FST: Project Details & Results



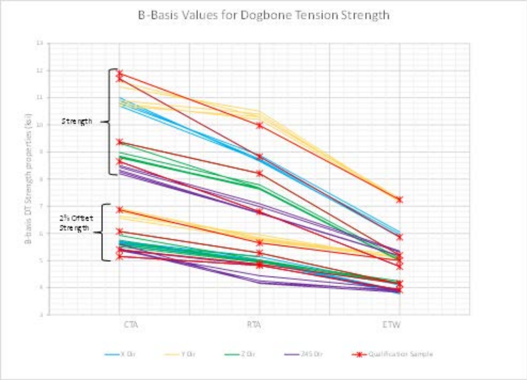
•*Infill style used in builds*

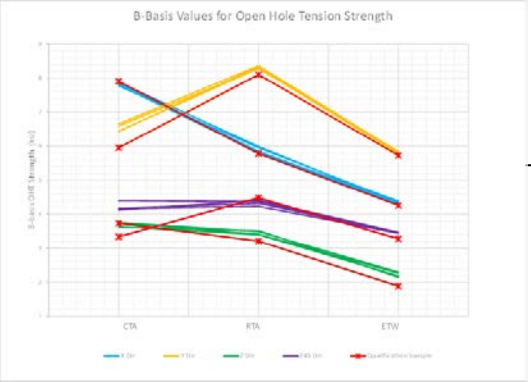
•*Pre (left) and post-test (right) vertical burn test specimens*

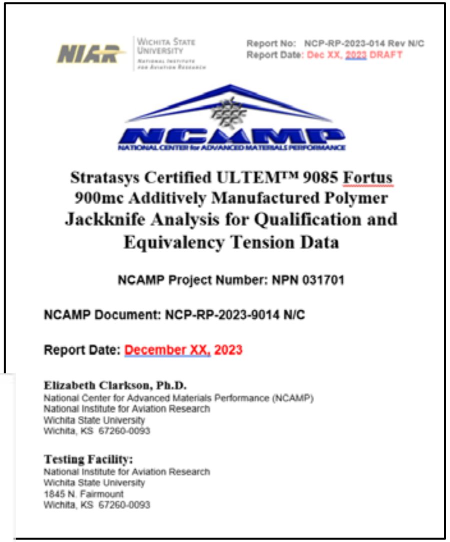
ULTEM 9085 Equivalency Studies

- Four companies produced an equivalency data set (one batch, one machine, two runs) that could be combined with the original qualification sample for analysis.
- Equivalence tests were performed in accordance with section 8.4.1 of CMH-17-1G and section 6.1 of DOT/FAA/AR-03/19, “Material Qualification and Equivalency for Polymer Matrix Composite Material Systems: Updated Procedure.”
- Dogbone Tension (DT) and Open Hole Tension (OHT) were assessed.
- Material allowable values and acceptance/ equivalency criteria were computed to see how this “new” data set compares to the original qualification results.

Status: Report under final review at NCAMP







Report No: NCP-RP-2023-014 Rev N/C
Report Date: Dec XX, 2023 DRAFT

Stratasys Certified ULTEM™ 9085 Fortus 900mc Additively Manufactured Polymer Jackknife Analysis for Qualification and Equivalency Tension Data

NCAMP Project Number: NPN 031701

NCAMP Document: NCP-RP-2023-9014 N/C

Report Date: December XX, 2023

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Testing Facility:
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Wichita, KS 67260-0093

Concluding Comments

- ULTEM 9085 qualification leveraged for additional research studies to facilitate the understanding and application of ULTEM.
- Statistical analysis results should be discussed and presented at future CMH-17 meetings.
- Guidelines on best practices on developing material specifications for extrusion can be used for future industry guidance.
- Future standards that document best practices on testing material extrusion specimens can also be developed using data collected from these studies.

Deliverables

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2022	Qualification of Additively Manufactured Material Extrusion Thermoplastic and Lessons Learned
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Questions?

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