Relationship Between 3-D Printed Materials and Flammability

Presented to: Tenth Triennial International Aircraft Fire and Cabin Safety Research Conference

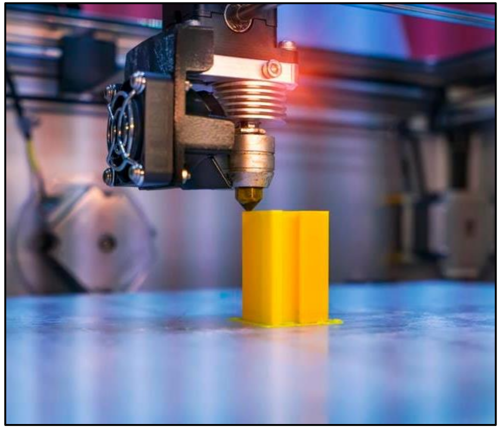
By: Dan Keslar and Steve Rehn

Date: October, 2022

Federal Aviation Administration

Introduction

- Additive Manufacturing (AM) is the process of joining materials, usually layer by layer, to produce an object
  - Commonly referred to as 3D printing
- Many different types of AM including:
  - Material Extrusion
  - Powder Bed Fusion
  - Binder Jetting
- For the purposes of this study, Fused Deposition Modeling (FDM), a type of Material Extrusion AM, was the primary focus



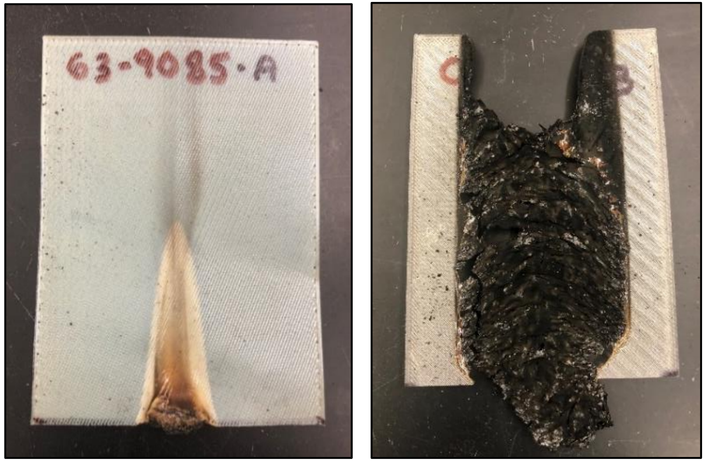
Introduction

- Aircraft manufacturers have interest in the use of AM produced parts within the cabin
  - 3D printed parts are currently used within small components such as fold down tray tables and arm chair rests within certain airlines
  - AM market is projected to grow significantly within the aerospace industry in the next 5 – 10 years
- Additive Manufacturing presents new challenges due to the different variables that are used in the production process

Test Objective

- Testing was conducted to determine how different print variables affect a 3D printed part’s flammability
- Experiment results will be used to simplify future flammability testing
  - By determining what would be considered a “worst case scenario” for each variable, future guidance could simplify certification testing
- All tests were conducted using the procedures in the 12 second Vertical Bunsen Burner (VBB) test handbook

VBB Test Measurements



Burn Length – the distance (in) from the sample edge to the farthest evidence of combustion damage

Flame Time – the time (s) that the specimen continues to flame after the burner flame is removed

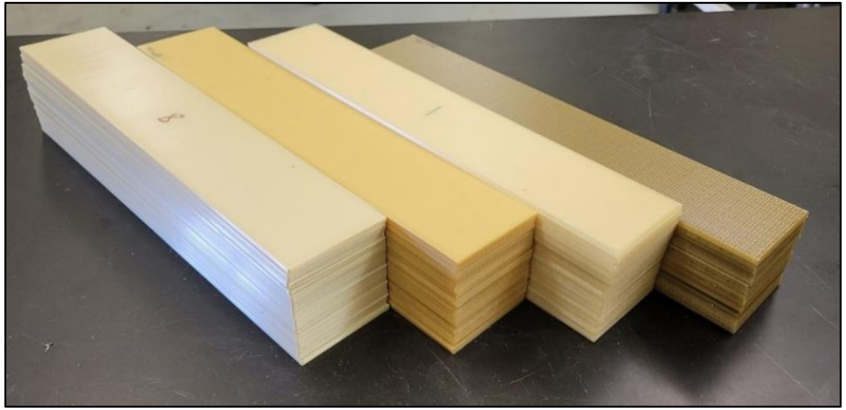
Drip Flame Time – the time (s) that any flaming material continues to flame after falling to the bottom of test chamber

Previous Testing

- Past testing was conducted in which one factor at a time (OFAT) was altered
- Several variables were identified as factors which affect flammability:
  - **Material**
  - **# Inner Layers**
  - **Infill Percentage**
  - **Infill Pattern**
  - **Raster Thickness**
  - **Raster Angle**
  - **Print Orientation (XY, YZ, ZX)**
- OFAT testing results indicated that all variables above had impact on flammability, but infill percentage, material and # inner layers had largest effect
- Different style testing was needed to determine if any of the variables had interaction effects – Design of Experiments

Design of Experiments (DOE) Setup

- 120 16” x 3” samples were printed
  - Samples were cut into fourths, in which 480 4” x 3” samples were tested
  - Samples and factors were randomized
- The factors that were altered in this study included:
  - Material
  - # of Inner Layers (Sample Thickness)
  - Infill % (Space Between Rasters)
  - Infill Pattern
  - Raster Angle
  - Raster Width (Width of inner extruded material)



Materials from left to right: Ultem 9085, Ultem 1010, Ultem Support, and Antero 800 NA

Materials

Ultem 9085

Ultem 1010

Ultem Support

Antero 800 NA

Inner Layers (Sample Thickness)

0 Inner Layers

0.02” Thick

All samples of this thickness had 0% infill

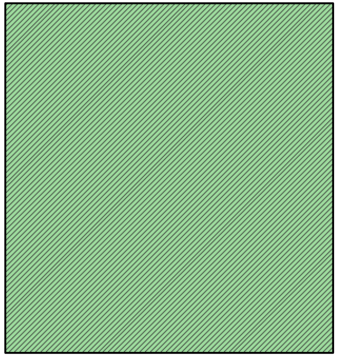
4 Inner Layers

0.08” Thick

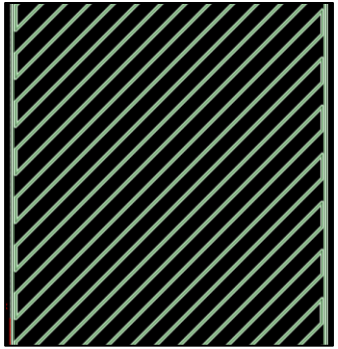
11 Inner Layers

0.15” Thick

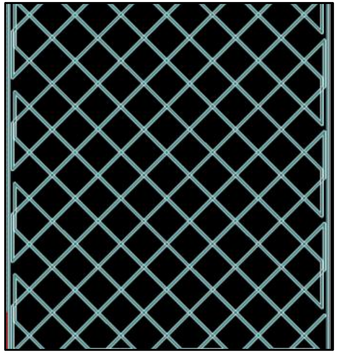
Infill Pattern



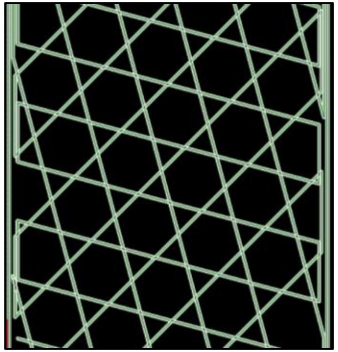
Solid (100% Sparse infill)



Sparse

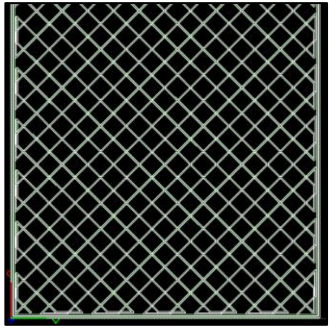


Sparse DD

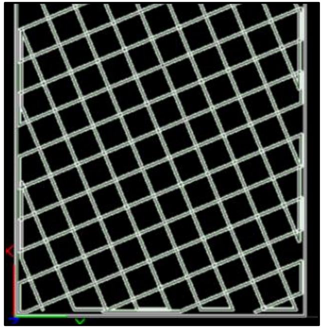


Hexagram

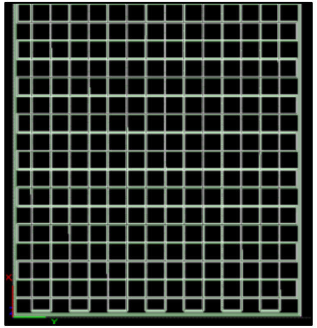
Raster Angle



45°



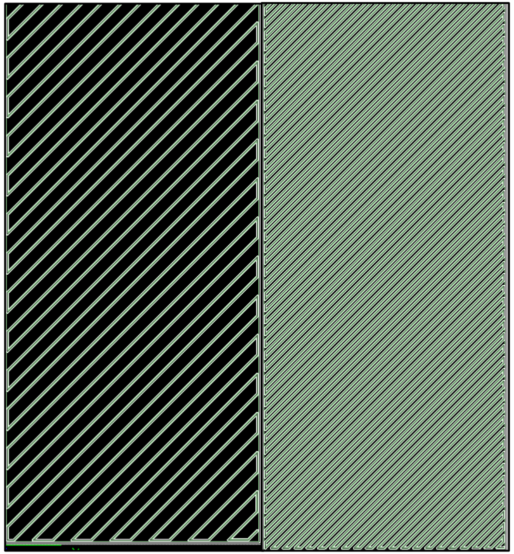
67.5°



90°

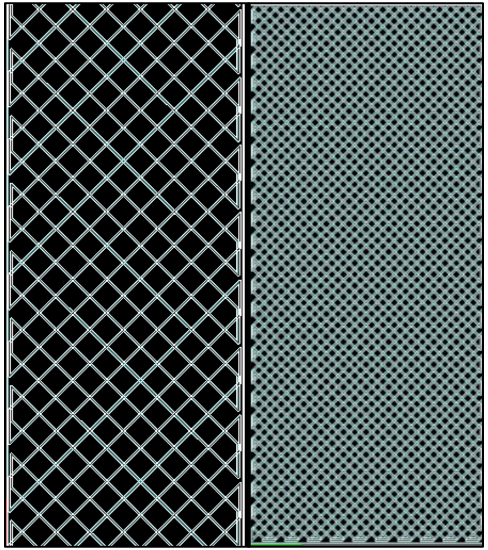
Infill Percentage Comparisons

Sparse



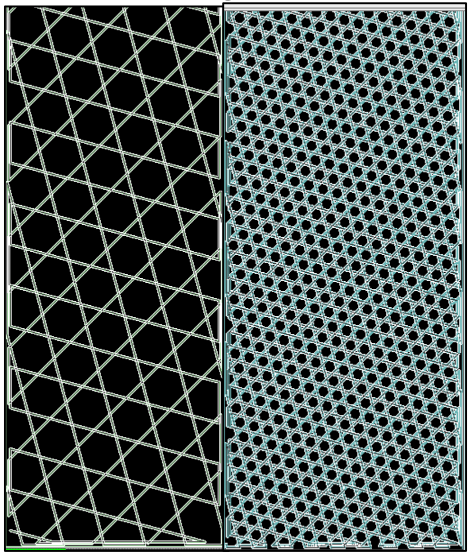
20% **60%**

Sparse DD



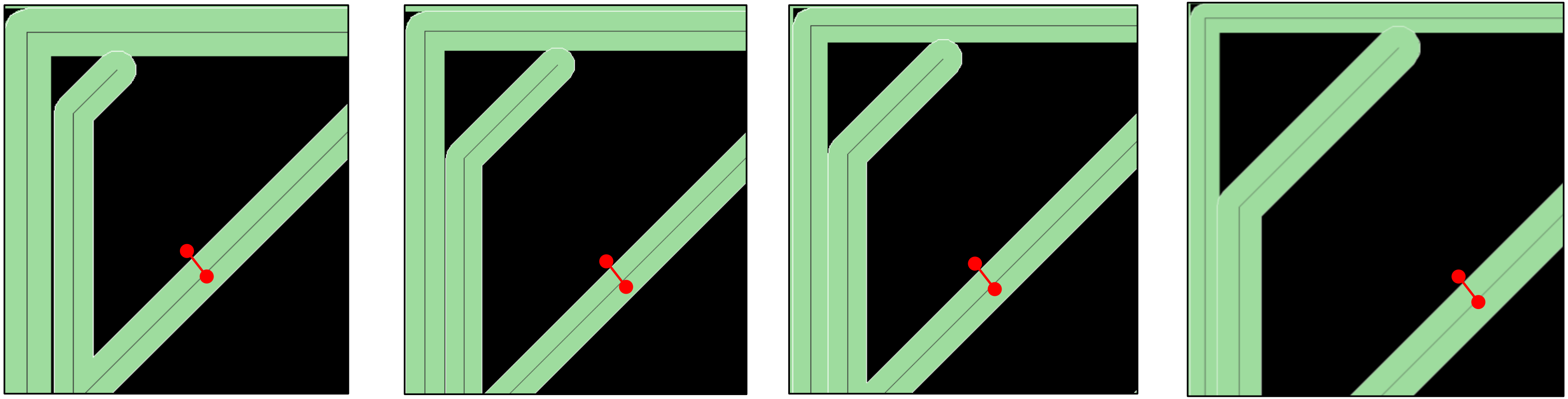
20% **60%**

Hexagram



20% **60%**

Raster Width Comparisons



0.016" Width | 0.018" Width | 0.022" Width | 0.030" Width

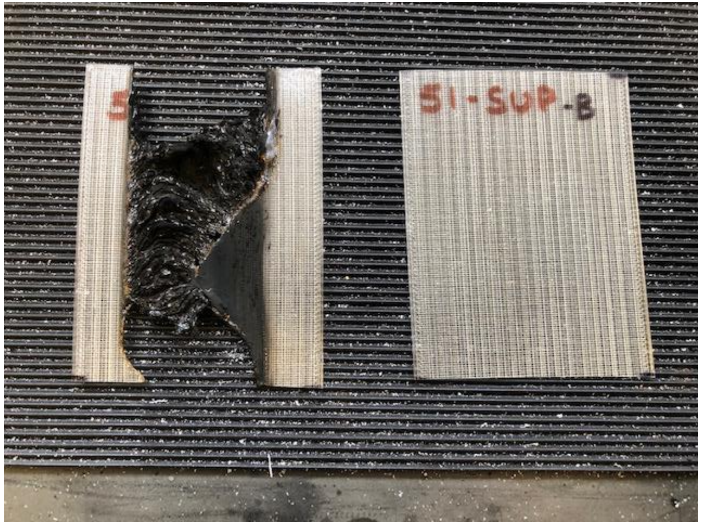
- Difficult to see, but the thickness of the extruded inner material increases from left to right
- Not visible in pictures of actual samples

Exceptions

- Due to constraints with the 3D printers, some combination of factors could not be created
  - Antero 800 NA samples could not be created at a raster width of less than 0.018”, so all 0.016” Antero samples were changed to 0.018”
  - All 60% infill hexagram with raster sizes of 0.016”, 0.018” and 0.022” were removed. All 0.030” samples were kept.
- These changes did not significantly affect the DOE data analysis

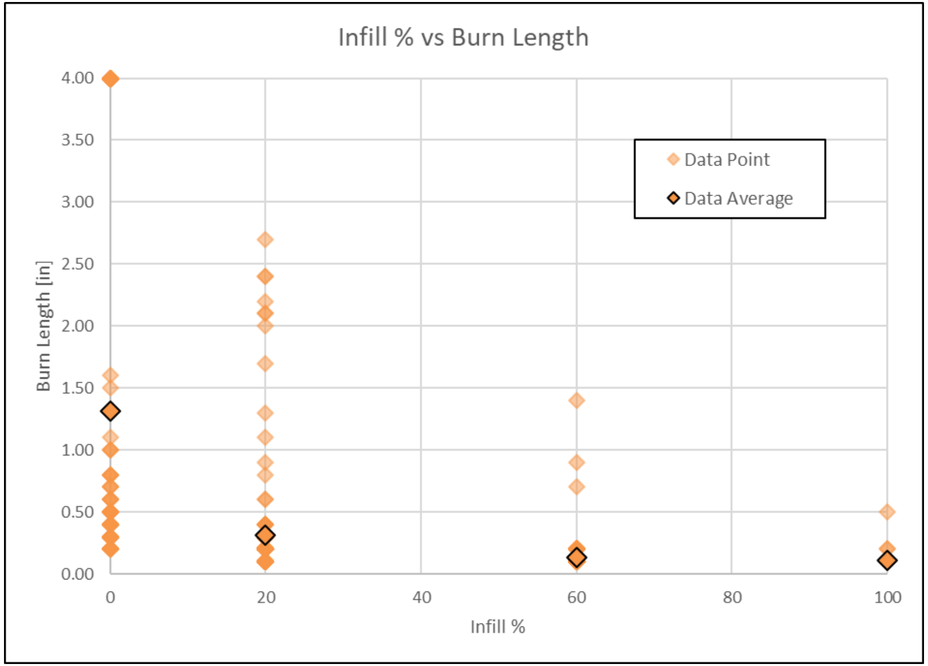
Observations

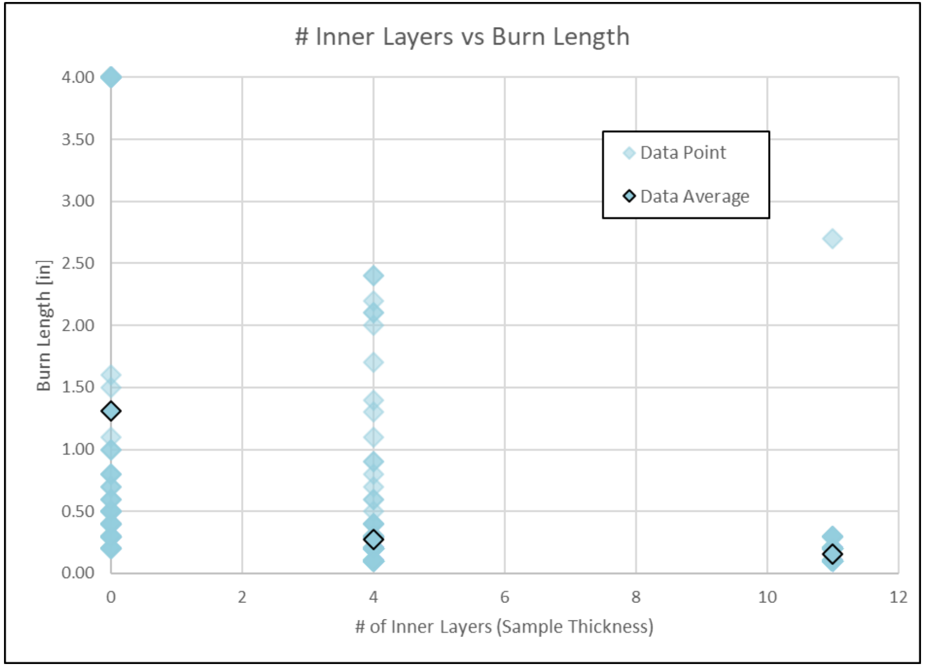
- As expected, Ultem Support was the most flammable material
  - Highest burn length, flame time and only material to experience drip flame time
  - All samples with a burn length greater than 4.0” were Ultem Support with 0 inner layers
- Samples with more inner layers and higher infill percentages were observed to perform better



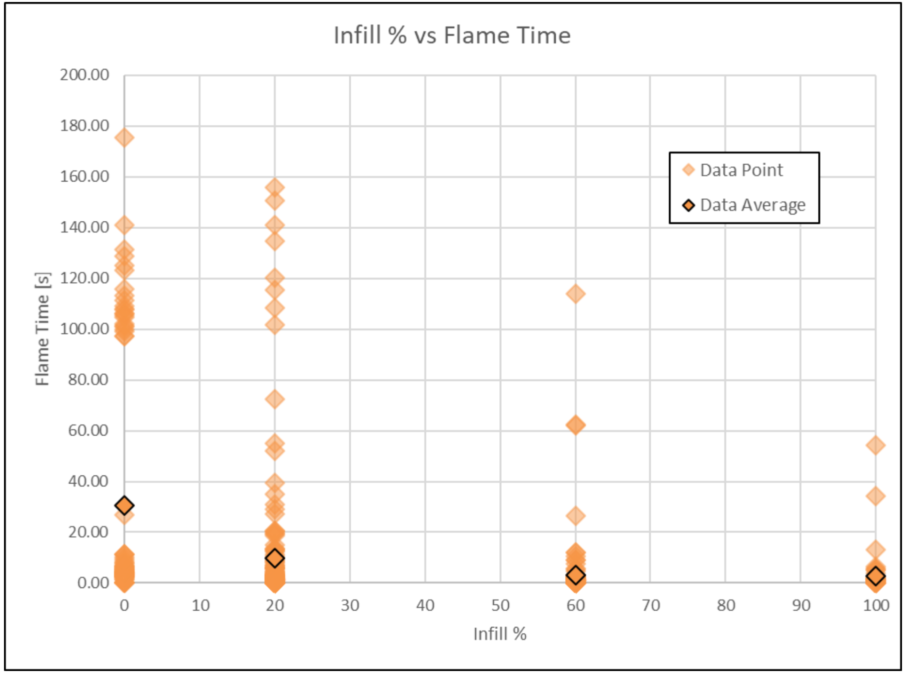
0 inner layer Ultem Support sample w/ > 4.0” burn length

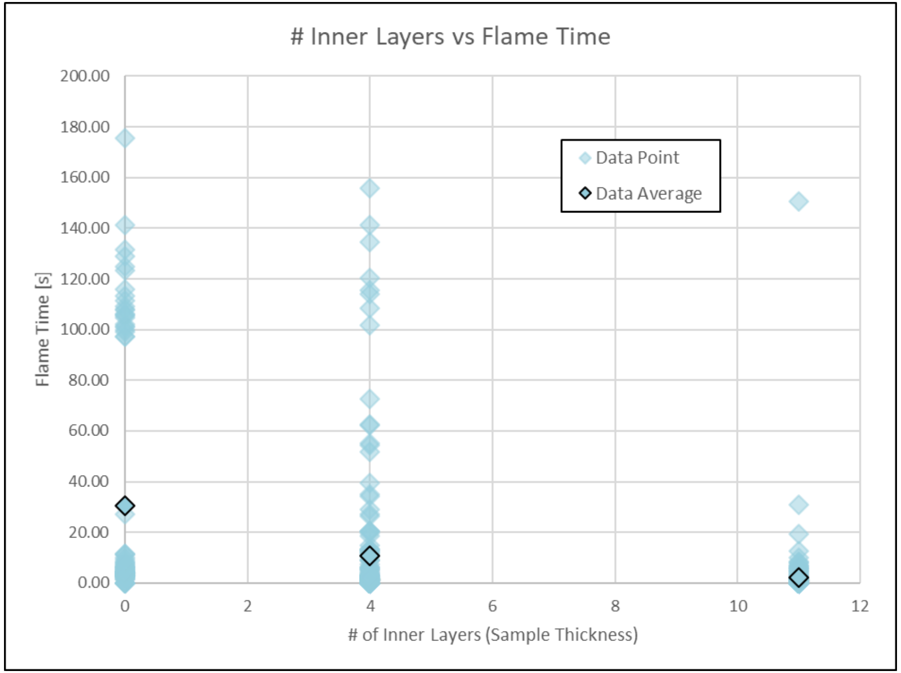
Infill % and # Inner Layers – Burn Length





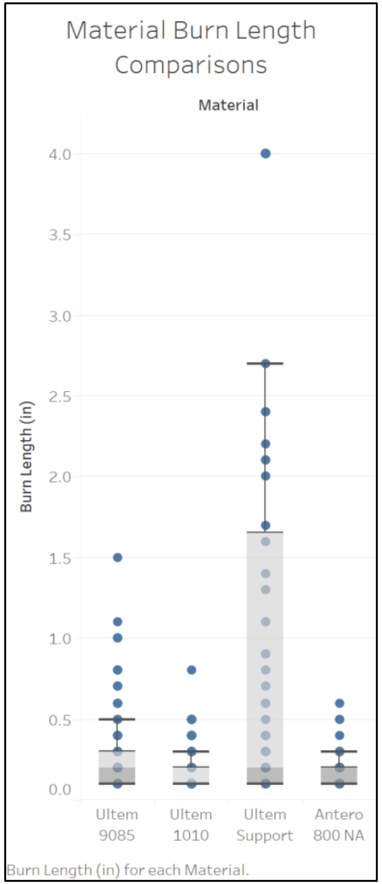
Infill % and # Inner Layers – Flame Time

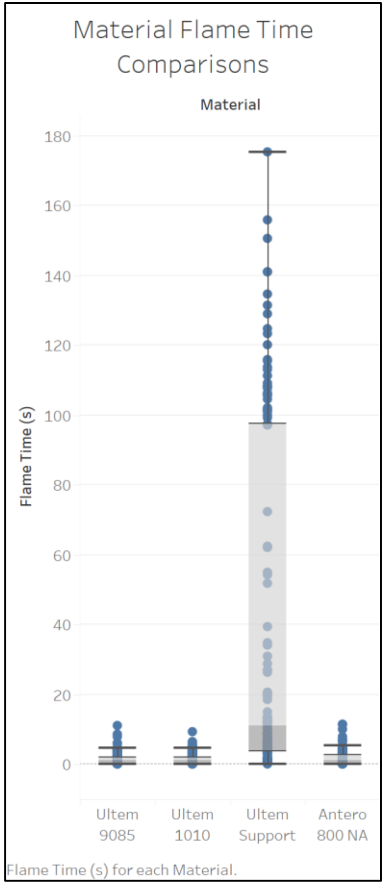




DOE Analysis

- All variables were significant as either main or interaction effects for predicting burn length
- All factors except for infill pattern were significant for predicting flame time
  - Material, # of inner layers, and infill % most significant variables for flame time and burn length
  - Raster width and raster angle less significant as main effect variables, but significant as interaction effect variables
- Material was the most significant variable in the occurrence of drip flame
  - Drip flame only occurred for Ultem Support materials, but was present with all other variable changes





DOE Analysis (Continued)

- 10 best and worst case flammability scenarios were generated on the combinations below for each material
  - Infill Pattern (None, Sparse, Sparse DD)
  - Raster Width (0.016” to 0.030”, by 0.002”)
  - Raster Angle (45° to 100°, by 7.5°)
  - Inner Layers (0, 4 to 11, by 1 layer)
  - Infill Percentage (0%, 20% to 60% by 10%)

Generated Best Case Scenarios – Ultem 9085

- Samples with higher infill % and inner layers created optimal conditions
- Infill pattern, raster width and raster angle dependent on material
  - Ultem 9085 mainly Sparse and 0.016” raster widths
  - Ultem 1010 primarily Sparse DD and 0.030” raster widths

Ultem 9085 - Top 10 Combinations for Minimization					
Rank	Infill %	Infill Pattern	# Inner Layers	Raster Angle [°]	Raster Width [in]
1	60	Sparse	11	90	0.016
2	60	Sparse	11	82.5	0.016
3	50	Sparse	11	90	0.016
4	60	Sparse	11	90	0.016
5	60	Sparse	11	75	0.016
6	50	Sparse	11	82.5	0.016
7	40	Sparse	11	90	0.016
8	60	Sparse	10	90	0.016
9	60	Sparse DD	11	90	0.016
10	60	Sparse	11	82.5	0.016

Generated Worst Case Scenarios – Ultem 9085

- Samples with 0 inner layers (0% infill) maximized burn length and flame time
- Raster angles and raster width varied

Ultem 9085 - Top 10 Combinations for Maximization					
Rank	Infill %	Infill Pattern	# Inner Layers	Raster Angle [°]	Raster Width [in]
1	0	None	0	90	0.016
2	0	None	0	45	0.016
3	0	None	0	82.5	0.016
4	0	None	0	90	0.018
5	0	None	0	45	0.030
6	0	None	0	52.5	0.016
7	0	None	0	90	0.030
8	0	None	0	45	0.018
9	0	None	0	75	0.016
10	0	None	0	90	0.020

Conclusion and Future Work

- Testing will be conducted on the 10 best/worst case scenarios for each material in order to confirm the validity of the DOE results
- Repeat testing may be needed to validate results
- Other suggestions at task group meeting?
- Goal is to eventually create guidance from results of testing

Questions?

Contact:

Steve Rehn
Federal Aviation Administration
William J. Hughes Technical Center
Fire Safety Branch, Bldg. 203
Atlantic City Int'l Airport, NJ 08405
(609) 485 - 5587
Steven.Rehn@faa.gov

Dan Keslar
Federal Aviation Administration
William J. Hughes Technical Center
Fire Safety Branch, Bldg. 203
Atlantic City Int'l Airport, NJ 08405
(609) 485-5767
Daniel.Keslar@faa.gov