Relationship Between 3-D Printed Materials and Flammability

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Introduction

- Additive Manufacturing (AM), also called “3-D Printing”, is a technology that introduces new parameters during material construction
- FAA has been researching how alterations in build parameters impact an AM part’s flammability
- Many different types of AM exist
- All testing within this study were on samples produced via Fused Filament Fabrication (FFF)

Objective

- Objective: Determine the worst case flammability scenario for each parameter to simplify future testing and certification
- Parameters were tested according to the Vertical Bunsen Burner (VBB) test procedures
- Three metrics are collected in this test:
  - Burn Length
  - Flame Time
  - Drip Flame Time

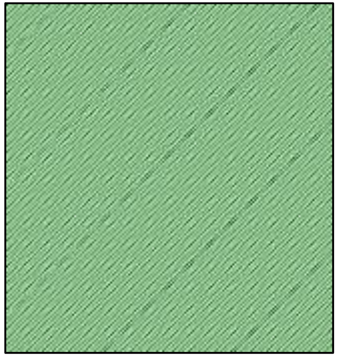
Previous Testing

- Previous testing was conducted in which one (or a few) factors at a time were altered:
- Evaluated parameters included:

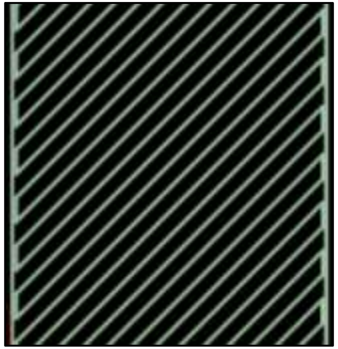
  1. Material
  2. Thickness(# of Inner Layers)
  3. Infill Percentage
  4. Infill Pattern
  5. Raster Thickness
  6. Raster Angle
  7. Print Orientation (XY, YZ, ZX)

- All parameters found to have some impact on data
- Material, thickness (# of inner layers), and infill percentage found to have the biggest impact on data

Infill Pattern

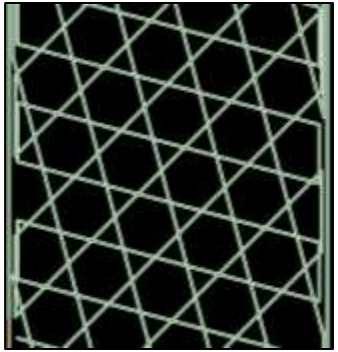


Solid (100% Sparse infill)



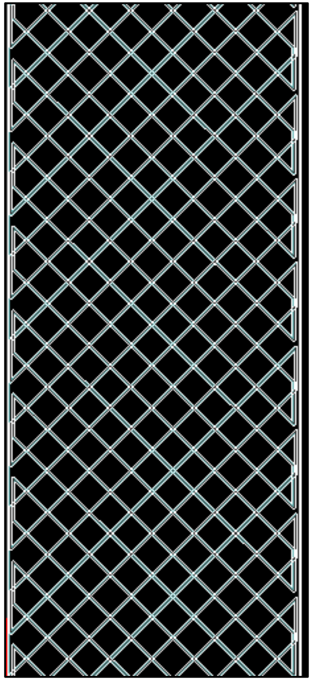
Sparse

Sparse DD

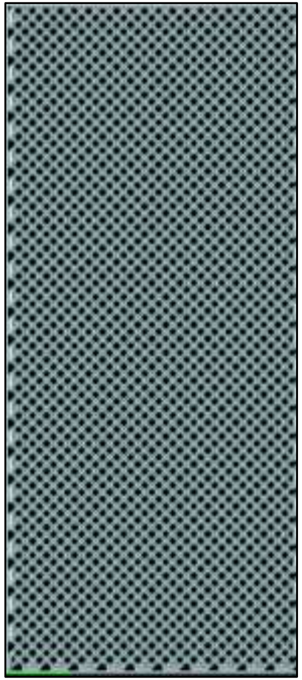


Hexagram

Infill %

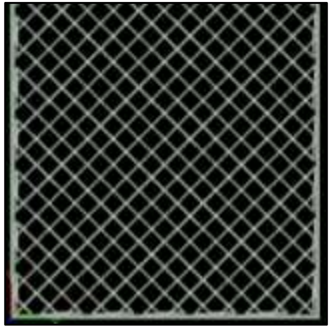


20%

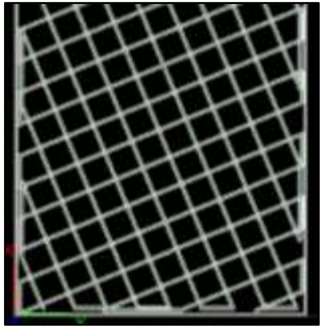


60%

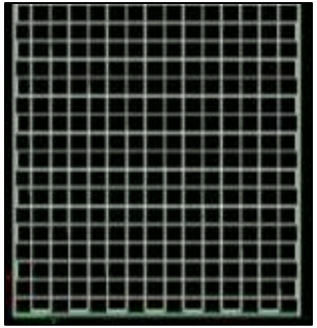
Raster Angle



45°

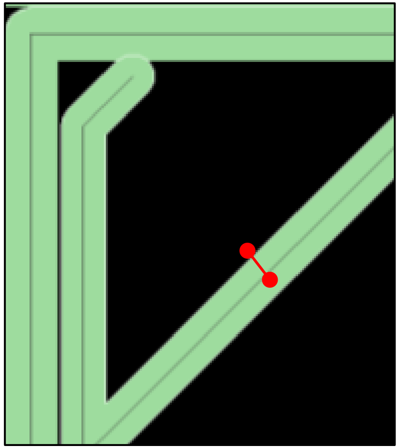


67.5°

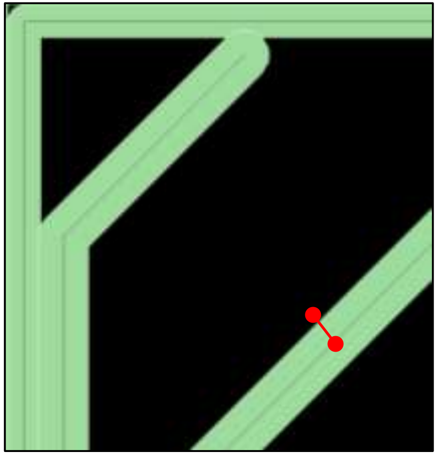


90°

Raster Width



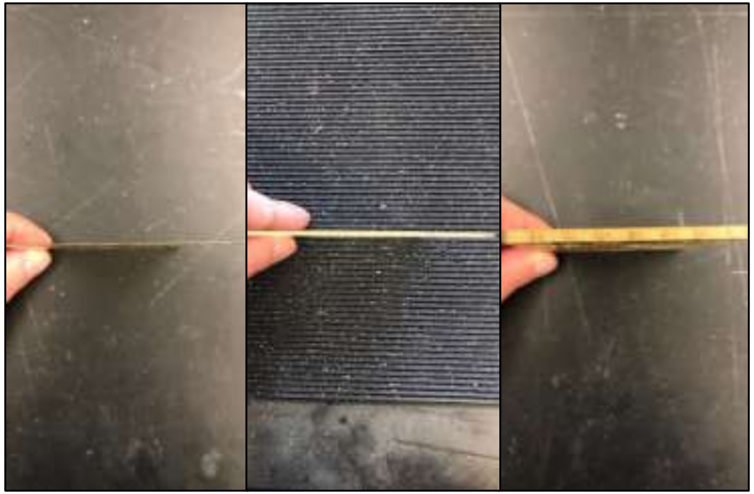
0.016” Width



0.030” Width

- Width of inner extruded material

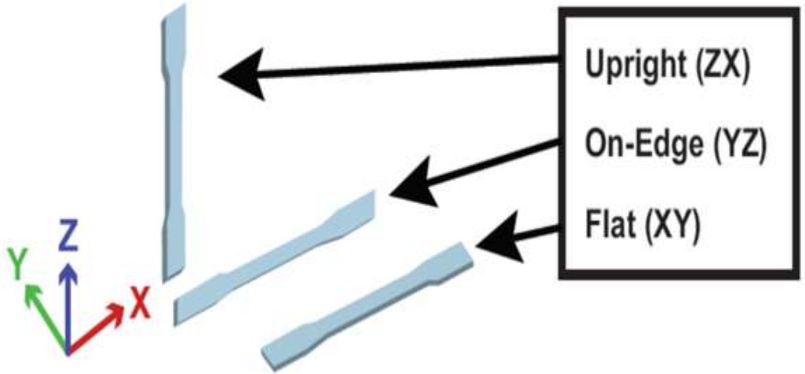
Thickness



0.02” **0.08”** **0.15”**

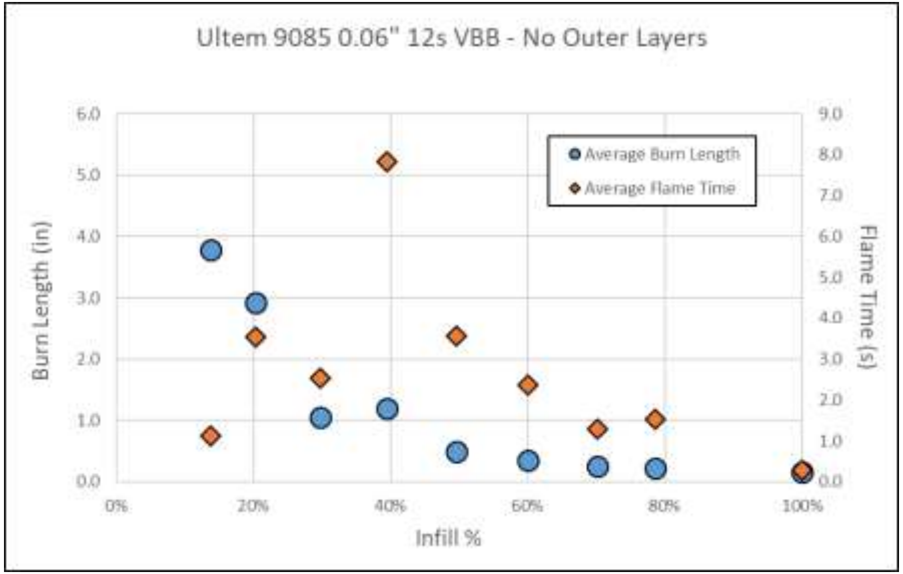
- Extruded layer thickness can be altered, but for our testing layer thickness was kept constant at 0.01”
- Therefore, thickness is directly correlated with the number of extruded layers (i.e 15 layers = 0.15”)

Print Orientation

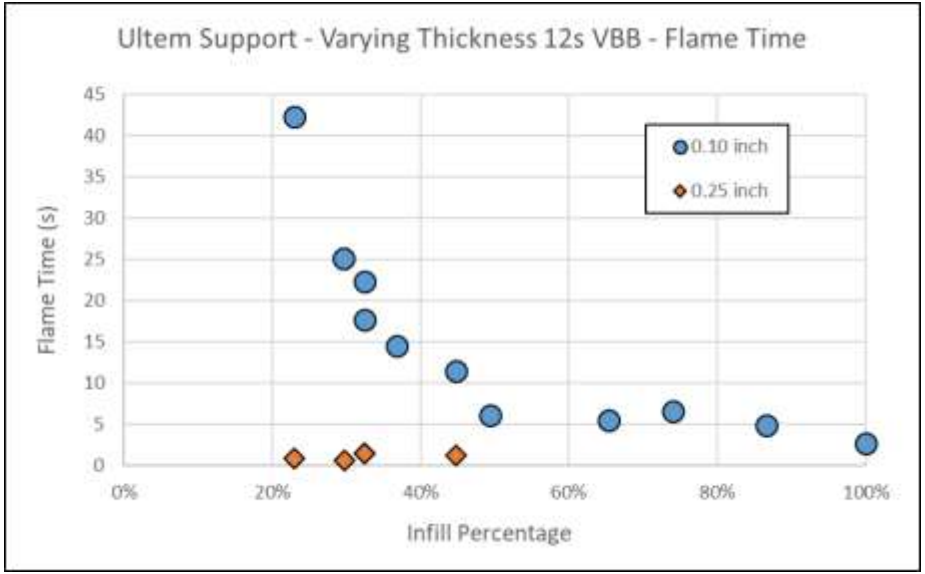


Examples of Infill % and Thickness Data

Infill % Comparisons



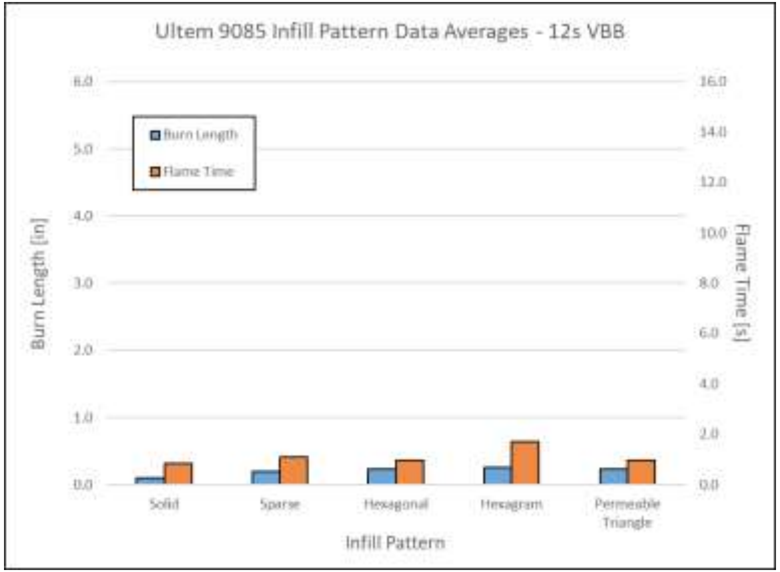
Thickness Comparisons



- Thicker and higher infill samples generally performed better

Examples of Infill Pattern and Print Orientation

Infill Pattern Comparisons



Print Orientation Comparisons

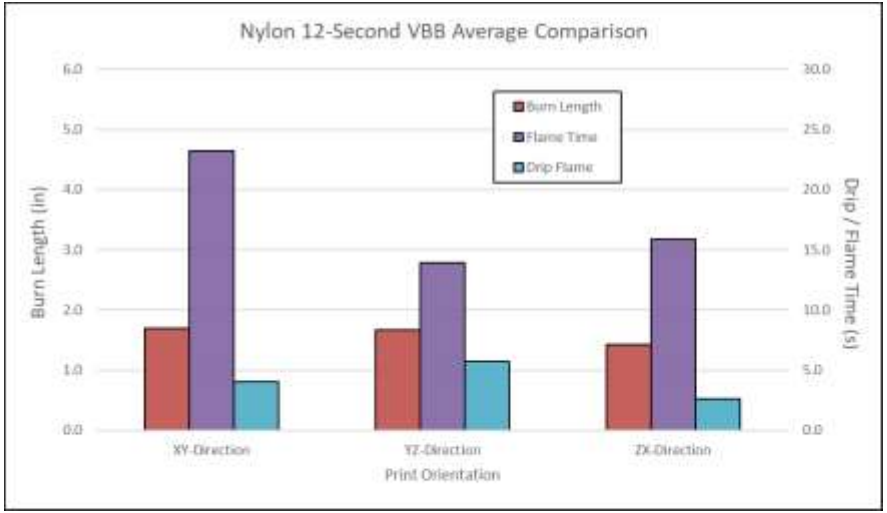
- As compared to other parameters such as Infill Pattern and Print Orientation in which there was very little difference in recorded data

Print Orientation Material Comparisons

Ultem 9085

*No Ultem 9085 samples recorded a Drip Flame Time

Nylon 12



- However, this observation changed depending on the evaluated material
- Larger difference between Print Orientations for Nylon 12, specifically in Flame/Drip Flame Time
- This suggests that different combinations of parameters may impact data

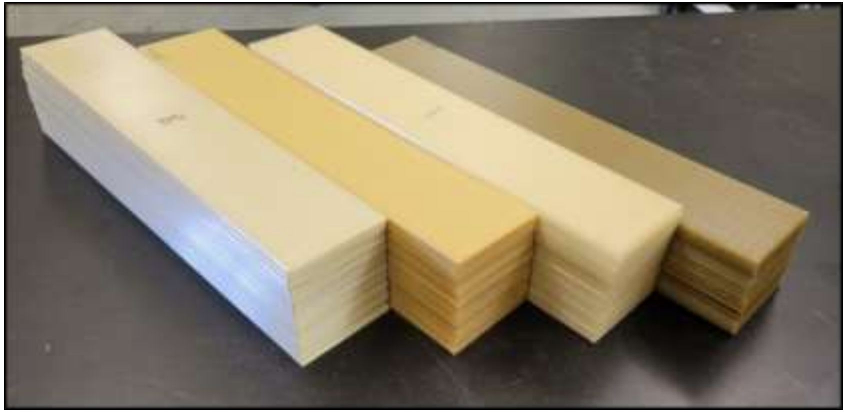
Design of Experiments (DOE) Testing

- Although altering a few parameters at a time provides a good comparison between data, it does not take into account interaction effects between various parameter combinations
- A Design of Experiments (DOE) test setup was performed to account for this

DOE Setup

- 120 16 x 3” samples were printed
  - Samples were cut into fourths, in which 480 4” x 3” samples were tested
  - Sample and factors were tested in a randomized sequence
- Factors altered within the DOE include:
  - Material
  - Thickness (# of Inner Layers)
  - Infill %
  - Infill Pattern
  - Raster Angle
  - Raster Width
- Print Orientation was not evaluated within this test series

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



Ultem Support is not commonly used as a material in produced parts, rather it is the support material of Ultem 9085

DOE Results

- All parameters significant as either main or interaction effect for predicting burn length
  - Material, thickness (# of inner layers), and infill percentage were the most significant main effect parameters
  - Raster width and angle are significant as interaction effect parameters
- All parameters **except** infill pattern were significant in predicting flame time
  - As raster angle increased, flame time was observed to increase quadratically (i.e 90° angles burned longer than 45° samples) in thinner samples

Generated Worst + Best Case Scenarios

- From the DOE data, ten "worst" and "best" case scenarios were generated for each of the evaluated materials
  - Combinations with less inner layers were most common among "worst" case scenario
  - Combinations with higher inner layers and infill percentages as well as Sparse or Sparse DD patterns minimized burn length and flame time
  - Raster widths and angles depended on the material

Additive Manufacturing Technical Note

- Technical note “DOT/FAA/TCTN-23/65” is in the process of being published which will include full results from current FAA testing
- Major conclusions include:
  - All parameters had an impact on the flammability of a 3-D printed part
  - Material type, sample thickness and infill percentage were the three parameters observed to have the most significant effect on data
  - Other parameters had limited to no direct impact on flammability
  - All evaluated factors significant as interaction effects in conjunction with other print parameters

Issue Paper

- Issue Paper is in the process of edited/reviewed which will provide further guidance – main points include:
  - PEI and PEI-PC samples above a certain thickness and infill percentage are likely to pass FAR 25.853 requirements
  - Test data from a thinner construction substantiates a thicker construction made of the same material and printing parameters
  - Data from testing a lower infill substantiates a higher infill percentage of the same material and printing parameters
  - Test data from the lowest and highest raster widths substantiates all raster widths in between for the same material and printing parameters.
  - Data from testing the lowest and highest layer thicknesses substantiates all layer thicknesses in between for the same material and printing parameters.

Future Steps

- Additional testing on other FFF parameters will be needed
  - Various layer thicknesses
  - Extrusion flow rate
  - Extruder temperature
  - Nozzle diameter
  - Extruder movement speed
- Different parameters present in other AM types

Questions?

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