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CTE Measurement for Polymer AM

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Polymer

- The Boeing company has been utilizing SLS for flight hardware in regular production since 2002/2007, for both military[2] and commercial[3] programs
- 787 was the first BCA program to utilize; weight and assembly benefits, other processes and applications are being developed

[2] Hauge R., Wooten J., Rapid Manufacturing: an industrial revolution for the digital age, Chapter 15, Page 233, John Wiley & Sons Ltd., UK, 2006
[3] Lyons, B., Deck, E, Bartel, A, Commercial Aircraft Applications for Laser Sintered Polyamides, SAE Technical Paper 09ATC-0387

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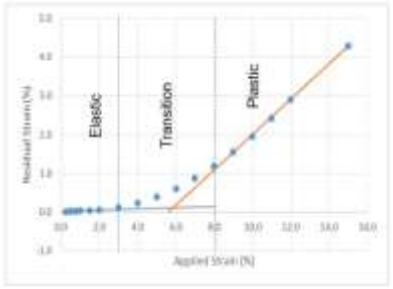
- Test coupon design

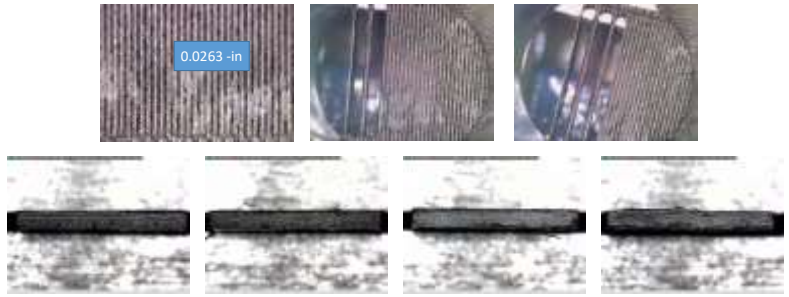
Ref: 2018 Presentation

- Data analysis method



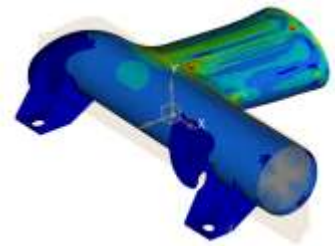
Ref: 2019 Presentation

- CTE testmethod



2020 Presentation

- Component level validation



Shared with ASTM, SAE & CMH17-AM

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Background

- CTE testing is typically accomplished with a small specimen via a thermomechanical analysis (TMA) test method as described in ASTM E831
- This has generally been found to be an acceptable approach for Selective Laser Sintering (SLS) processing and standard Fused Filament Fabrication (FFF) processing
- ASTM E831 states, "*Specimens shall be between 2 mm and 10 mm in length and have flat and parallel ends to within 625 µm. Lateral dimensions shall not exceed 10 mm*"
- For large-diameter-FFF the unit cell of the material/process can exceed the test sample size
- The specimens used for the standard TMA testing may not be appropriate when testing very large filament extrusion additive materials

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Approach

- With the FFF process, the filament width and layer thickness can be considered a unit cell of the process
- Investigation performed utilized multiple tests to establish a minimum ratio between the material/process unit cell dimensions and the test specimen size in order to produce accurate CTE values for FFF part
- The use of the smaller filament FFF machine is intended to serve as a model for the CTE measurement issues that have been identified on the larger filament FFF builds
- Material purchased for the testing was produced to internal Boeing material specification requirements

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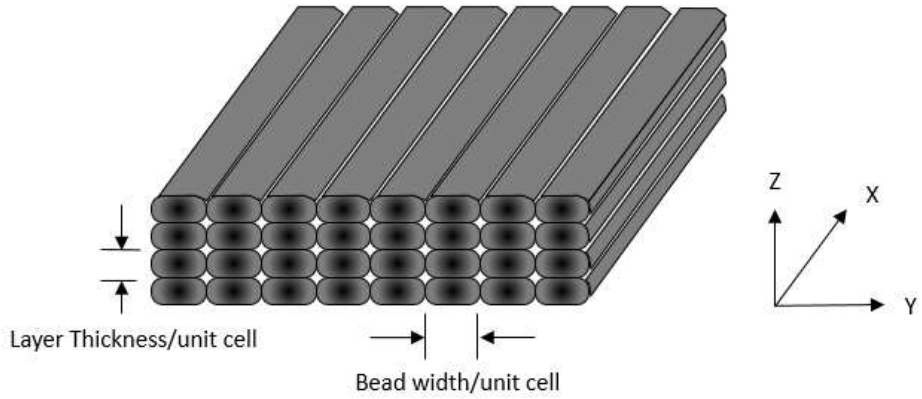
Specimen Fabrication

- Carbon-filled PEKK material specimens were printed using the FFF process
- The FFF process for the investigation utilized a 0.020 inch diameter tip
- The extruded 0.020 inch diameter filament is compressed by the FFF process to form a 0.013 inches tall x 0.026 inches wide layer on the part
- All the layers in each sample are identical and aligned with the top layer through-out the sample
- The use of all-parallel fill is not typical of FFF builds but served the purpose of this testing to create aligned filaments across the test sample
- Subsequent machining operations were performed to obtain desired specimen dimensions and configurations



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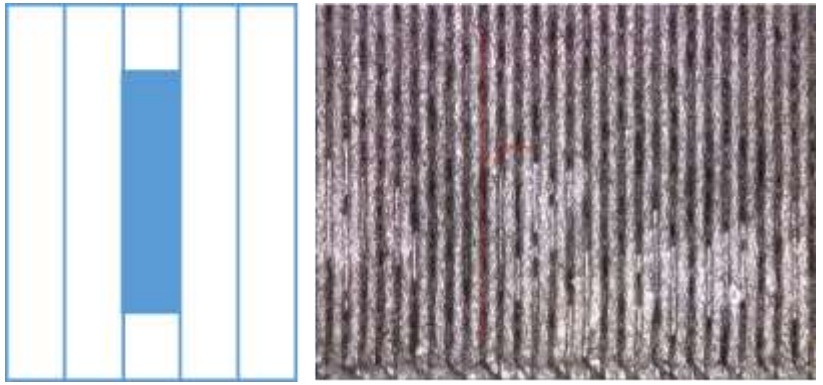
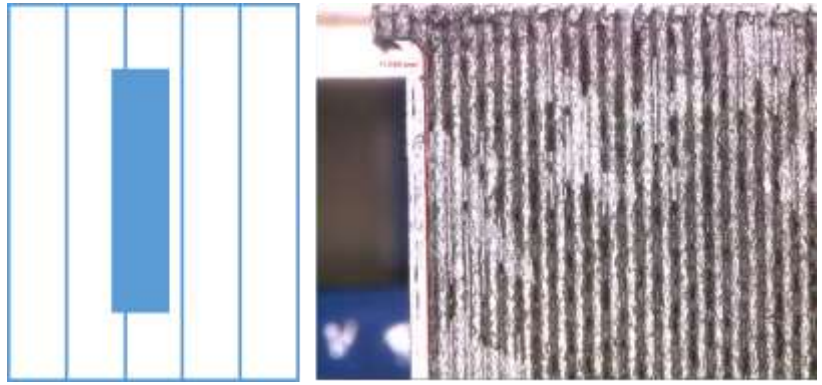
Specimen Fabrication (continued)

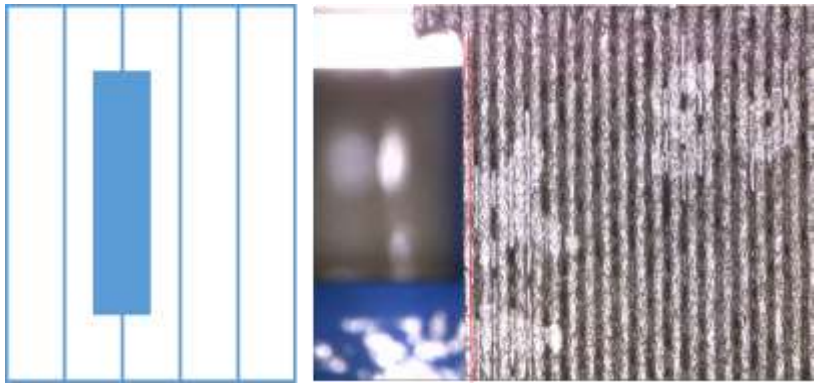
- For the specimen that included partial layers (<1 unit cell), a CNC machine was used to cut the partial layers. A program was created to ensure a correct 25%, 50%, and 100% layer was produced
- A digital microscope was used to visualize the individual layers of the specimens. A microscopic image of a ruler was taken to convert the pixel measurements into inches



100% of a Layer Schematic



25% of a Layer Schematic



50% of a Layer Schematic

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Unit Cell Size CTE Testing

- The purpose was to develop a relationship between the process unit cell size and the minimum CTE test specimen size necessary to produce repeatable test data
- The test data also need to represent the overall part/tool CTE behavior and not localized CTE behavior
- It was expected that measurements perpendicular to the placement direction and predominant fiber direction will exhibit greater test variability than measurements taken parallel to the filament and predominant fiber direction

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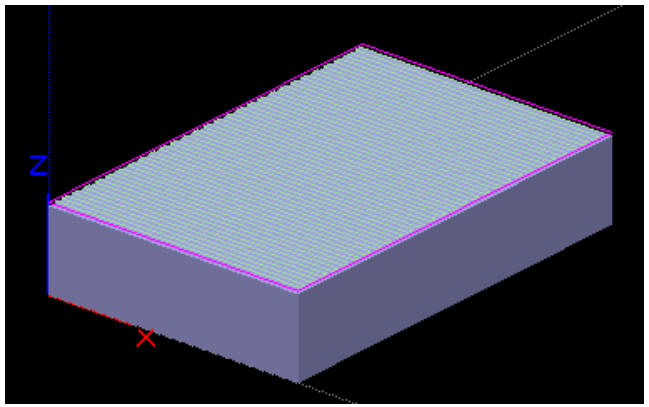
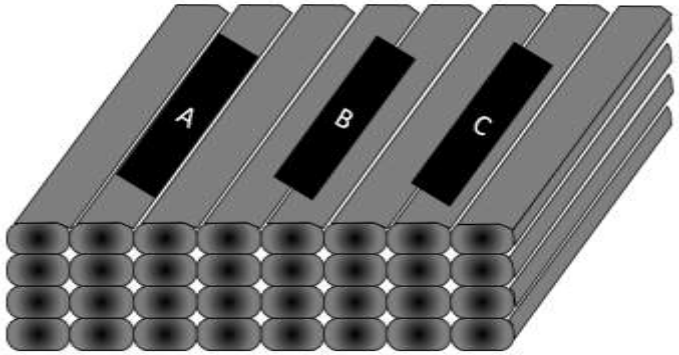
Unit Cell CTE Test Matrix

Test Method	Specimen Description	Build Direction	Environmental Conditioning	Material	Sample Thickness	Qty.	Testing Temp.	Test Direction
ASTM E831 with variations	1 unit cell – index with layers	YXZ / 0 dir	Dry	CF-PEKK	0.026	3	-100°F to 300°F	Y
	1 unit cell – 50% off layers				0.026	3		Y
	1 unit cell – 25% off layers				0.026	3		Y
	3 unit cell – Index with largest error from 1 unit cell				0.078	3		Y
	5 unit cell – Index with largest error from 1 unit cell				0.130	3		Y
	7 unit cell – Index with largest error from 1 unit cell				0.182	3		Y
	15 unit cell – Index with largest error from 1 unit cell				0.390	3		Y



Build direction



A- Unit cell indexed with layers
B- Unit cell indexed 50% off of layers
C- Unit cell indexed 25% off of layers

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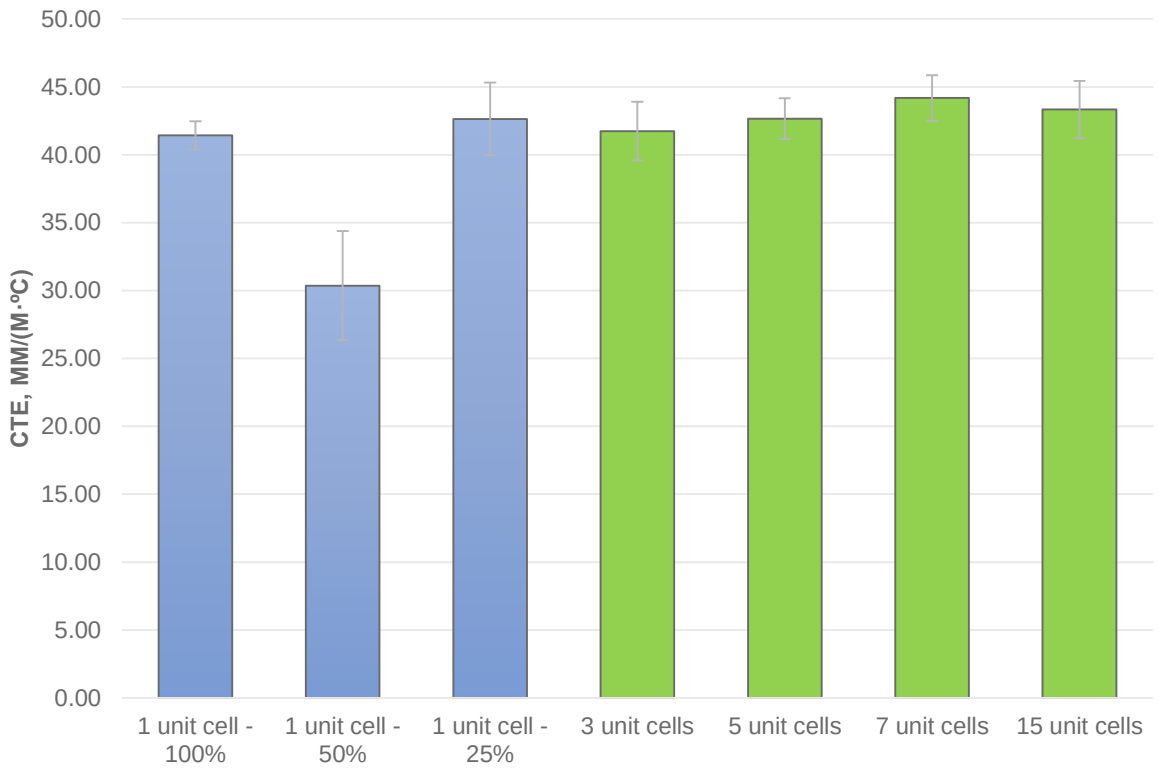
Test Results

- Thermomechanical analyzer (TMA) was used to determine the linear thermal expansion of the and CF PEKK materials
- Test samples were subjected to a fixed heating rate
- Figure illustrates the CTE test results for different unit cell sizes in terms of layers
- The results show a variation in the test data when the specimen size is reduced to single (1) unit cell or less



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Summary

- Specimens with multiple unit cells show consistent data averages confirming that the minimum recommended unit cell size should be greater than one
- Although two (2) unit cell configuration was not tested, it is recommended the CTE test specimen fabricated by FFF process to capture at least three (3) layers or unit cells to produce accurate CTE results

The data presented here are produced by Boeing and NIAR under NASA Cooperative Agreement NNL09AA00A, Work Activity 2C27. Disclosure, use and duplication of the data are governed by NASA Cooperative Agreement NNL09AA00A, Activity 2A38, Exhibit B, 1(b)(5).

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