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Correlation of ULTEM 9085 Physical, Chemical, and Mechanical Properties

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Motivation, Objective, and Approach

- Motivation and Key Issues
  - Obtain a better understanding of how the physical and chemical properities of AM ULTEM 9085 effect the mechanical performance
- Objective
  - Identify abnormal performance of AM ULTEM 9085 samples and develop theories for mechanical testing
- Approach
  - Review intial statistical analysis and further explore the data set
  - Development of theories for abnormal ULTEM 9085 performance
  - Print and test AM ULTEM 9085 coupons to explore theories

Correlation of ULTEM 9085 Physical, Chemical, and Mechanical Properties

- Principal Investigator & Researchers
  - John Parmigiani (PI); OSU faculty
  - Seth O’Brien; OSU grad student
- FAA Technical Monitor: Danielle Stephens
- FAA Sponsor: Cindy Ashforth
- Other FAA Personnel Involved: Larry Ilcewicz
- NIAR/NCAMP Personnel Involved
  - Royal Lovingfoss
  - Elizabeth Clarkson
- Industry Participation
  - Charles Evans; Stratasys

Today's Topic

ULTEM 9085 Qualification and FDM Background

Project Steps

Literature Review

Abnormal Performance in Qualification

Further Analysis of Qualification

Abnormal Performance Theories

Intial Testing Plan

AM ULTEM 9085

- ULTEM 9085
  - Polyetherimide and polycarbonate amorphous thermoplastic
  - Strength-to-weight ratio (480.5lb-in/g)
    - ABS 379.3 lb-in/g
    - PLA 378.3 lb-in/g
    - Nylon 610.9 lb-in/g
  - Flame, smoke, and toxicity (FST) characteristics
  - Currently used in aerospace and transportation sectors

ULTEM 9085 Qualification Background

- Planned and tested between 2016-2019 for the first PBAM qualification
- Fabricated by RP+M
- Tested at NIAR
- Analyzed by NCAMP statistician

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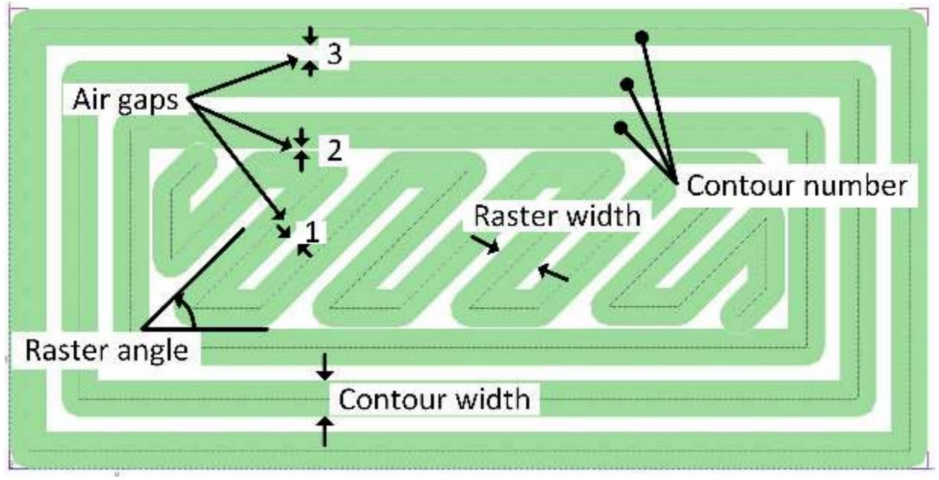
NCAMP
NATIONAL CENTER for ADVANCED MATERIALS PERFORMANCE

AM FDM Background



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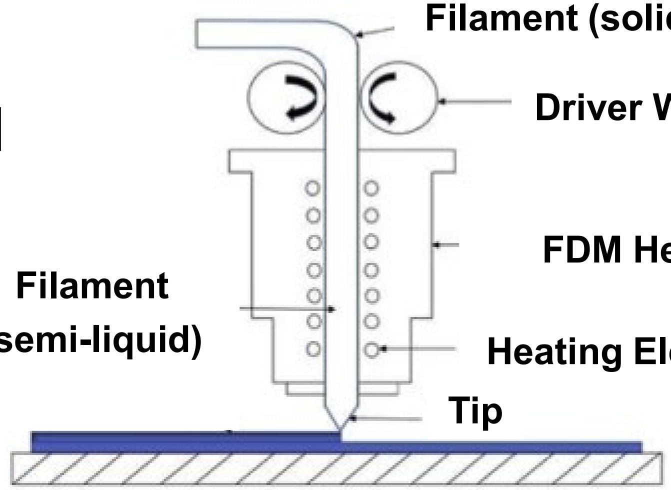

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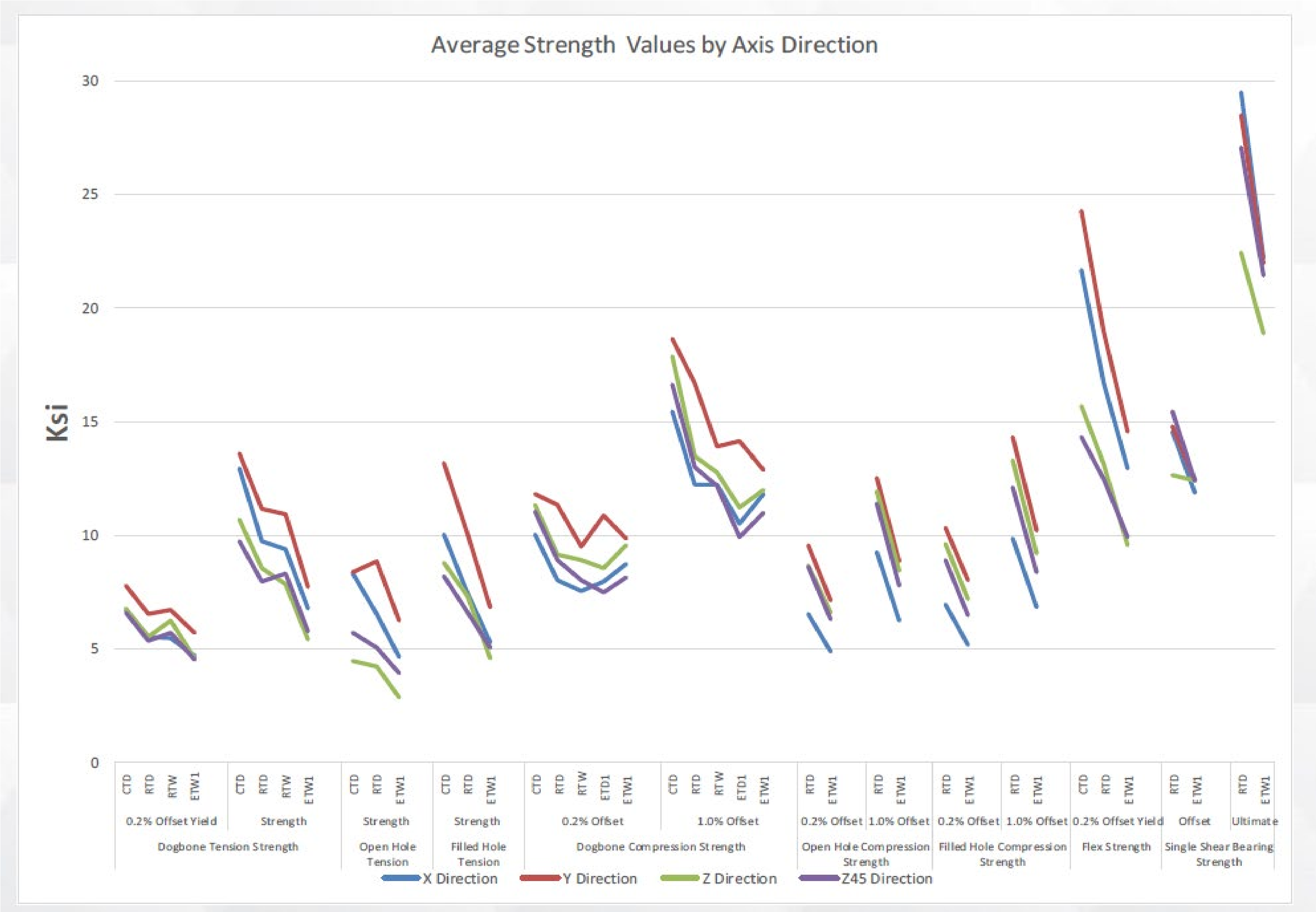
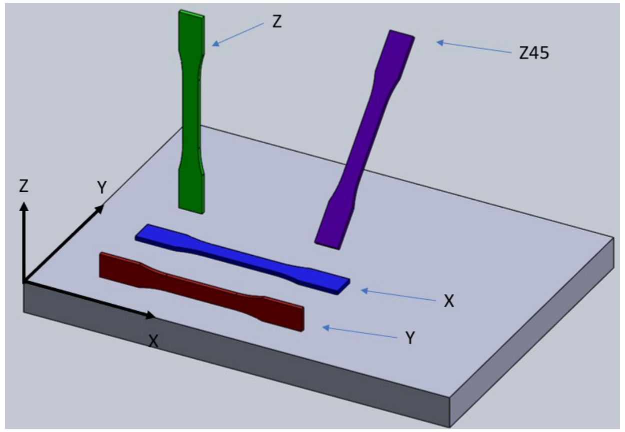
Qualification Parameters

- 1 contour
- ±45° raster pattern
- 0” air gap

Project Steps



- Identify abnormalities between orientations from intial analysis
- Analyze other sections of data
- Develop theories for abnormalities
- Test printed coupons to support theories



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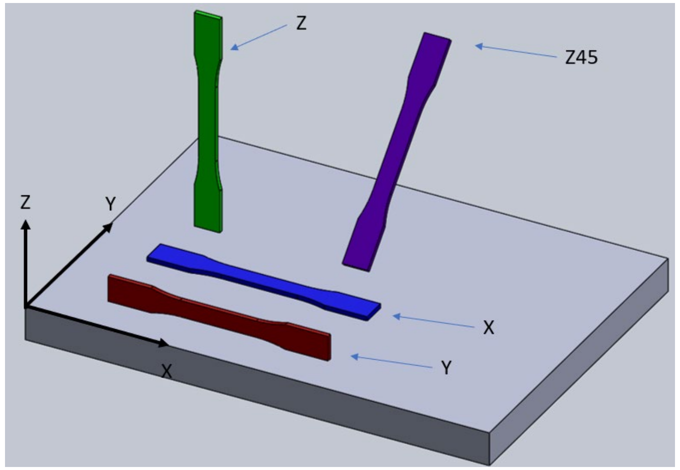
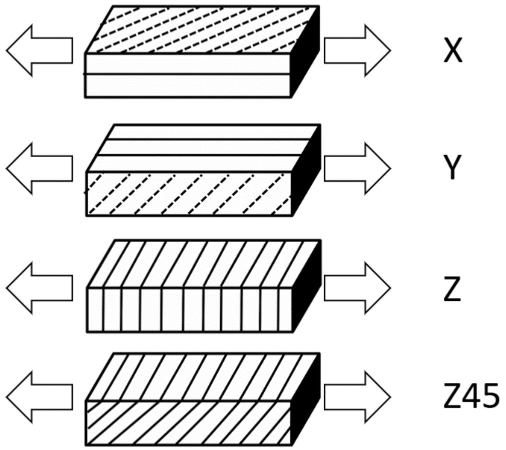
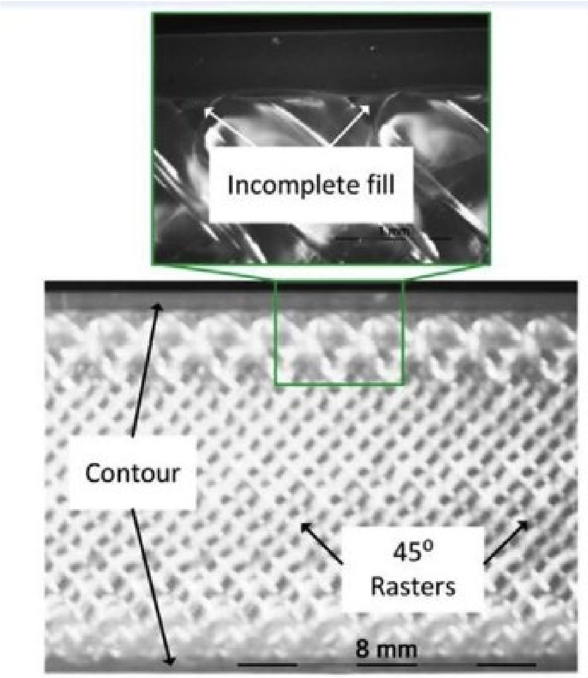
Literature Review

- X orientation has the lowest density of all orientations
  - Attributed to the contour-to-raster ratio [3]
- Tensile strength: Y>X>Z45>Z
  - Layers parallel to load direction = higher strength [4]
- Inter/intra layer necking effects mechanical properities
  - Relates to layer temperature at time of deposition [5]







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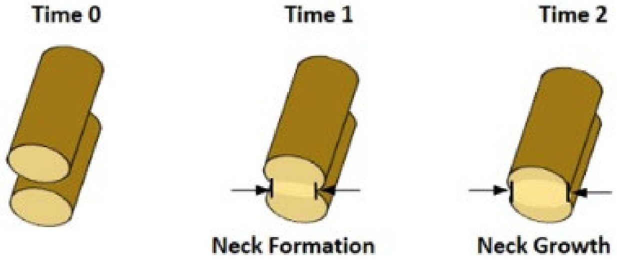
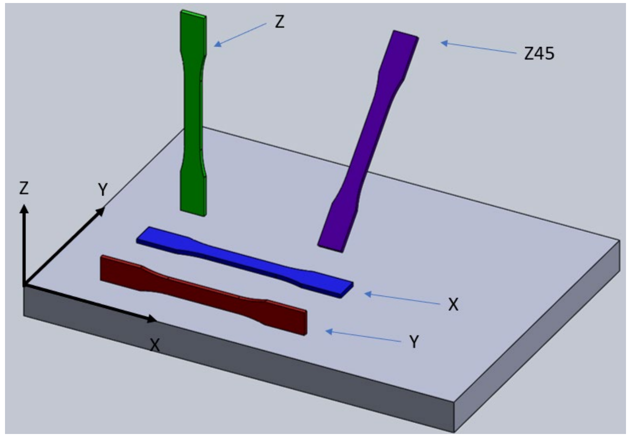
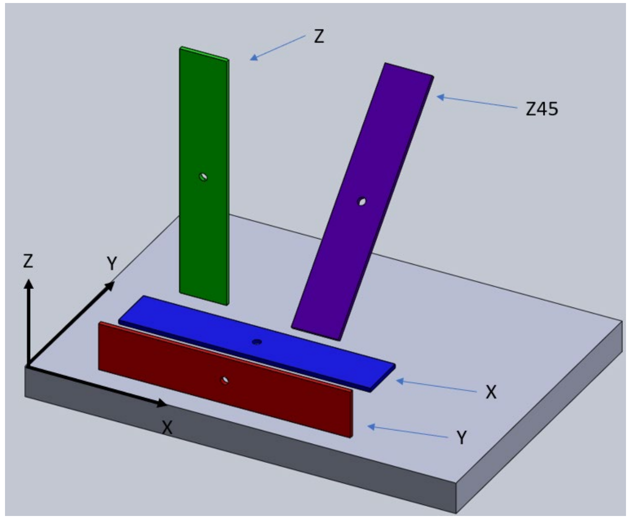


[5]

Abnormal Performance in Qualification

Test	Test Condition	Results	Observation
Dogbone Tension, 0.2% Offset Yield Strength	CTD	X, Z, Z45 combined	**Not expected, X>Z,Z45**
	ETW	X, Z, Z45 combined	**Not expected, X>Z,Z45**
	RTD	X, Z combined	**Not expected, X>Z**
Filled-Hole Tension, Strength	RTD	X, Z combined	**Not expected, X>Z**





Yield Strength Literature Comparison

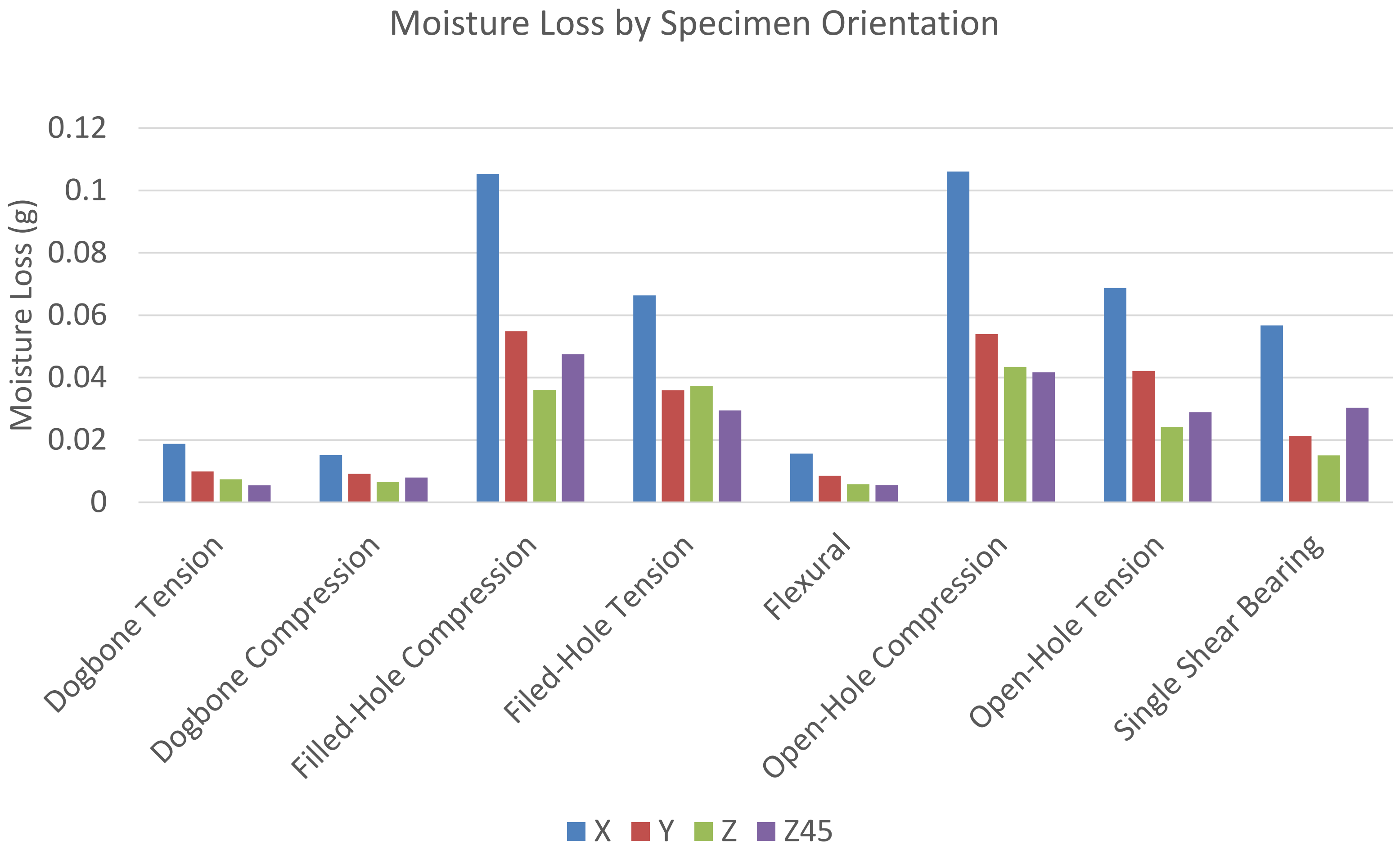
Source	Yield Strength ksi for Print Orientations			Replicates per Orientation
	Y	X	Z	
NCAMP (RTD)	6.56	**5.54**	**5.54**	24
[4]	7.94	**6.81**	**4.64**	5
[5]	5.30	**4.32**	**4.10**	4

Other two studies showed that X>Z for yield strength

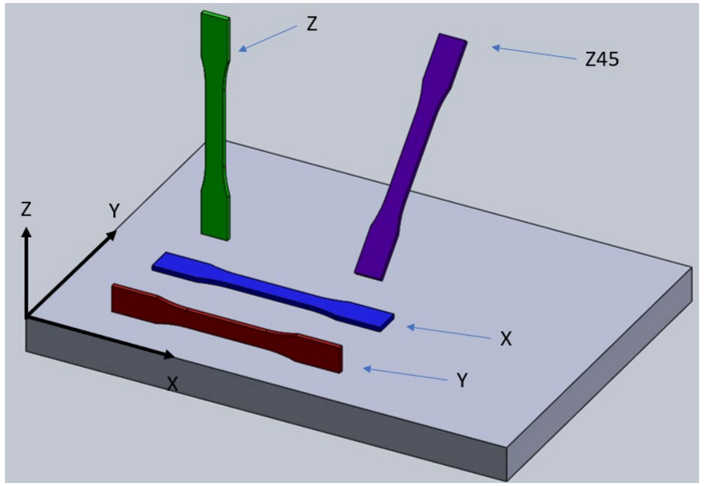
[4] Zaldivar, R. J., Witkin, D. B., McLouth, T., Patel, D. N., Schmitt, K., & Nokes, J. P. (2017). Influence of processing and orientation print effects on the mechanical and thermal behavior of 3D-Printed ULTEM® 9085 Material. Additive Manufacturing, 13, 71–80. https://doi.org/10.1016/J.ADDMA.2016.11.007

[5] Shelton, T. E., Willburn, Z. A., Hartsfield, C. R., Cobb, G. R., Cerri, J. T., & Kemnitz, R. A. (2020). Effects of thermal process parameters on mechanical interlayer strength for additively manufactured Ultem 9085. Polymer Testing, 81. https://doi.org/10.1016/j.polymertesting.2019.106255

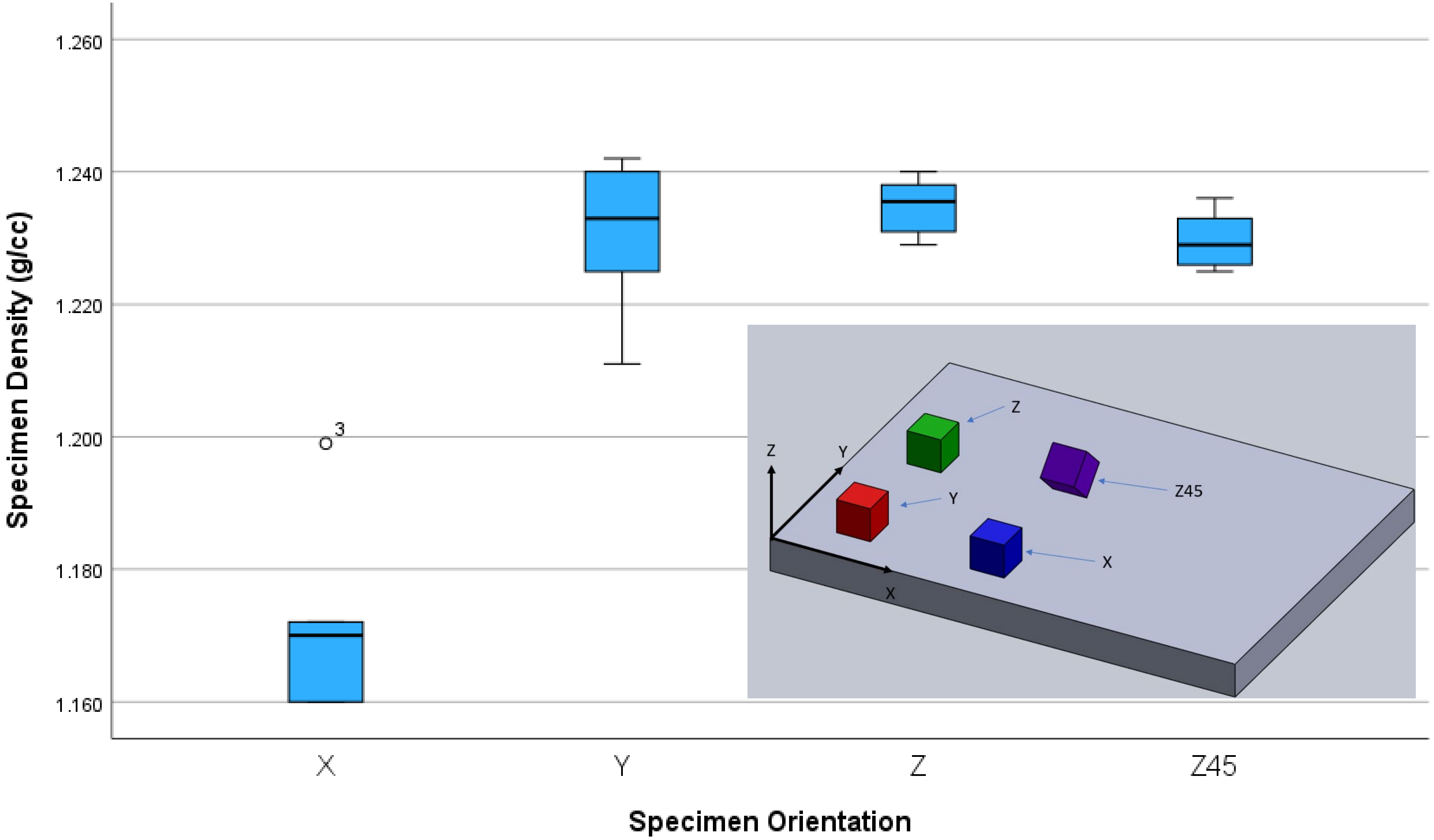
Further Analysis-Moisture Loss



X had higher moisture loss for all tests



Further Analysis-Specimen Density



- Lower density = higher porosity
- With print orientation shown, interesting that X, Y, and Z would be significantly different

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X Orientation Theory

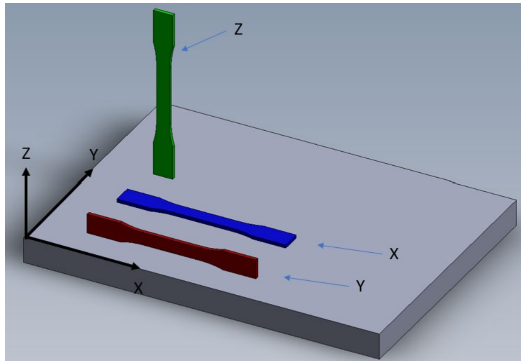
A combination of

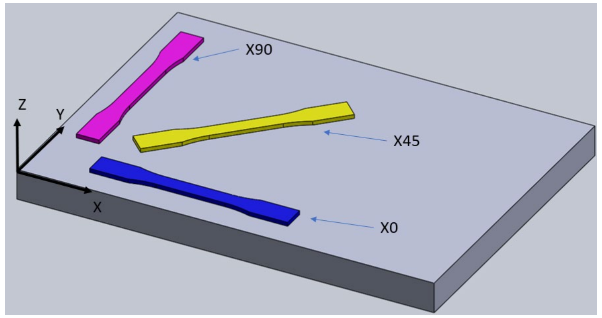
- higher void percentage
- less fusion between intra-inter layers due to area of layers

leads lower performance of X orientation

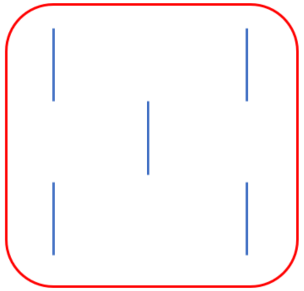
Intial Testing Plan

Abnormality	Test/Analysis	Orientation	Condition	Samples per Orientation	Total
Difference in cube densities	Relative Density	X, Y, Z	RTD	5	15
Retesting for yield and ultimate strength	Dogbone Tension (D638)	X, Y, Z	RTD	5	15
Coalances of layers and void percentage	Microstructure/ Macrostructure	X, Y, Z	N/A	5 50% printed	15
X orientation angles leading to differing strengths	Dogbone Tension (D638)	X0, X45, X90	RTD	5	15
Coalances of layers and void percentage	Microstructure/ Macrostructure	X0, X45, X90	N/A	5 50% printed	15





- One sample for each test printed at one of the 5 locations in printer
  - Reduce thermal gradient effect on samples
  - Consistent time between layer deposition



Coupon Build Configuration

Questions and comments are encouraged!

Thank you!

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