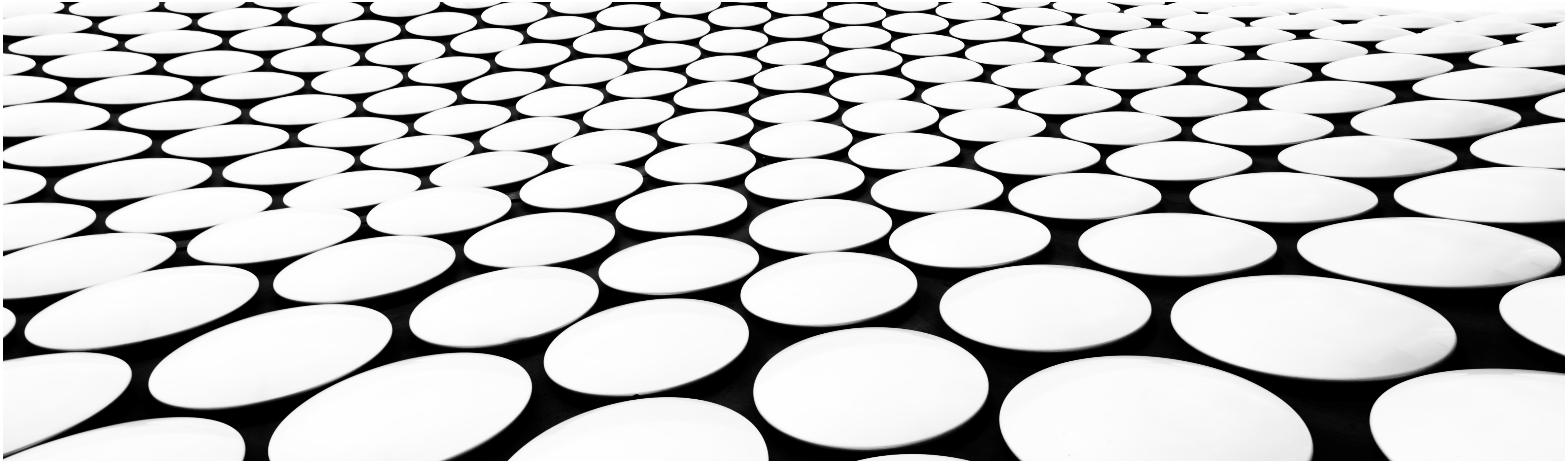
3D PRINTING ORIENTATIONS
AND HOW IT AFFECTS MATERIAL PROPERTIES

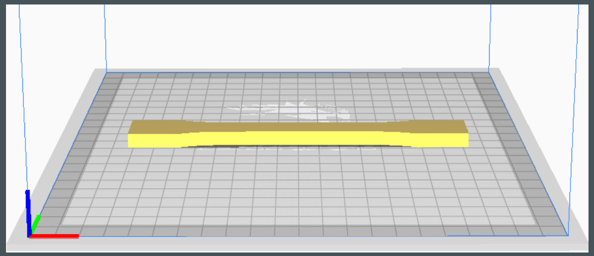
BY: BRYSON POTTS



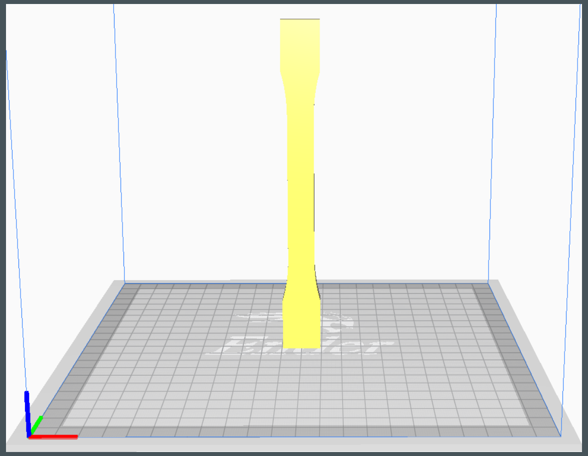
OBJECTIVE

DETERMINE THE TENSILE PROPERTIES OF POLYLACTIC ACID (PLA) WHEN PRINTED AT DIFFERENT ORIENTATIONS USING FUSED DEPOSITION MODELING (FDM)

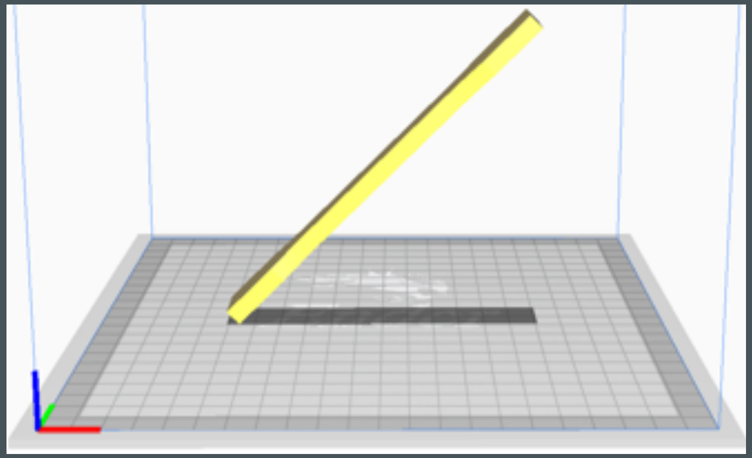
Zero Degrees (5 specimens)



90 Degrees (5 specimens)



45 Degrees (1 specimen)



EQUIPMENT

Creality Ender 3 Pro

MTS Criterion Model 43

Ruler

Neiko Calipers

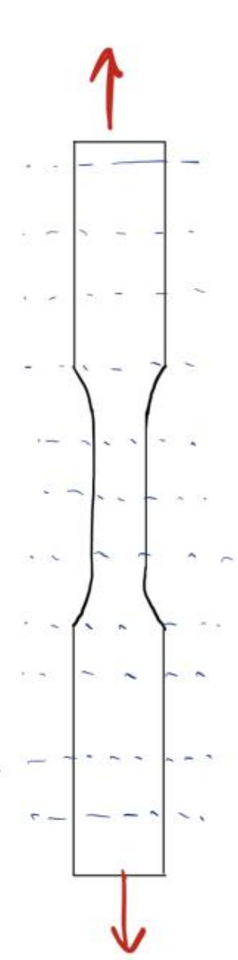
Hatchbox PLA

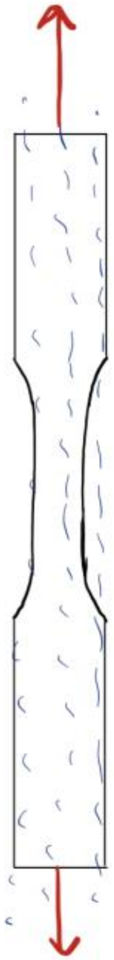
AUTODESK®
FUSION 360™

Cura

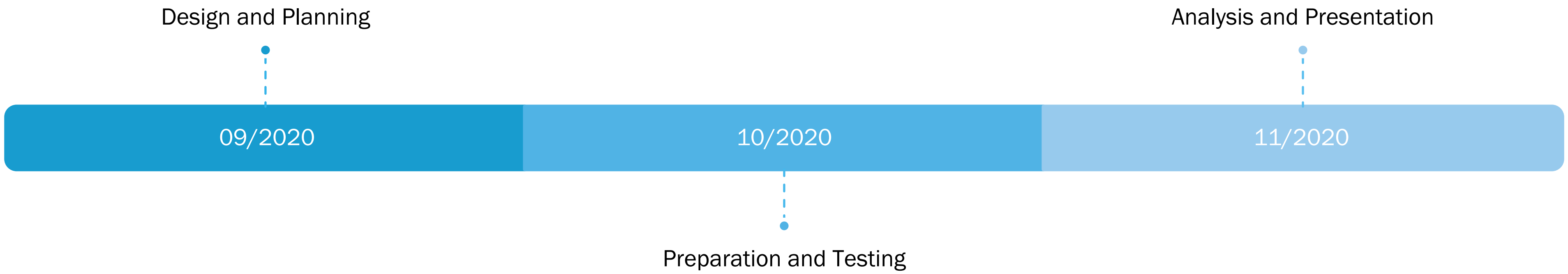
WHY IS THIS IMPORTANT?

- FDM is a process of additive manufacturing where extruded layers of material builds the object.
- The print orientation changes the direction of the layers in the print.
- It is expected that layers parallel to the tensile force would perform best. (0-degree print orientation)





THIS PROJECT CONSISTS OF THREE PHASES

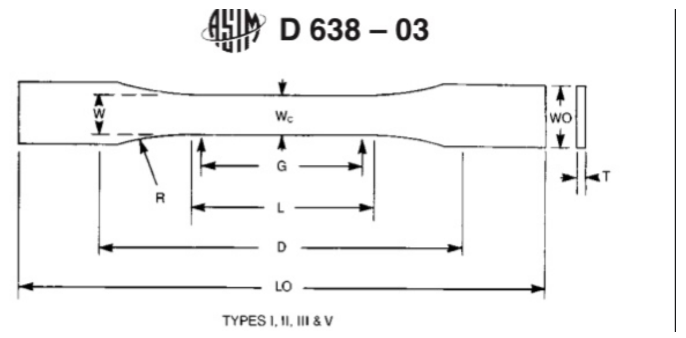


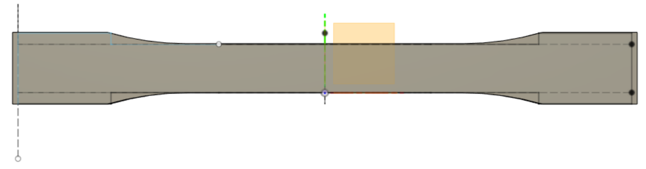
PHASE 1:
FUSION 360 DESIGN

- Fusion 360 is made by Autodesk
- It is easy to use for 3D modelling
- The specimen is modelled in mm
- The specimen was modelled to

ASTM D 638-03 Type 1 standards

Dimensions (see drawings)	Specimen Dimensions for Thickness, T, mm [in.][A]					Tolerances
	7 [0.28] or under		Over 7 to 14 [0.28 to 0.55], incl	4 [0.16] or under		
	Type I	Type II	Type III	Type IV[B]	Type V[C,D]	
W—Width of narrow section[E,F]	13 [0.50]	6 [0.25]	19 [0.75]	6 [0.25]	3.18 [0.125]	±0.5 [±0.02][B,C]
L—Length of narrow section	57 [2.25]	57 [2.25]	57 [2.25]	33 [1.30]	9.53 [0.375]	±0.5 [±0.02][C]
WO—Width overall, min[G]	19 [0.75]	19 [0.75]	29 [1.13]	19 [0.75]	...	+ 6.4 [+ 0.25]
WO—Width overall, min[G]	...	...	...	...	9.53 [0.375]	+ 3.18 [+ 0.125]
LO—Length overall, min[H]	165 [6.5]	183 [7.2]	246 [9.7]	115 [4.5]	63.5 [2.5]	no max [no max]
G—Gage length[I]	50 [2.00]	50 [2.00]	50 [2.00]	...	7.62 [0.300]	±0.25 [±0.010][C]
G—Gage length[I]	...	...	...	25 [1.00]	...	±0.13 [±0.005]
D—Distance between grips	115 [4.5]	135 [5.3]	115 [4.5]	65 [2.5][J]	25.4 [1.0]	±5 [±0.2]
R—Radius of fillet	76 [3.00]	76 [3.00]	76 [3.00]	14 [0.56]	12.7 [0.5]	±1 [±0.04][C]
RO—Outer radius (Type IV)	...	...	...	25 [1.00]	...	±1 [±0.04]

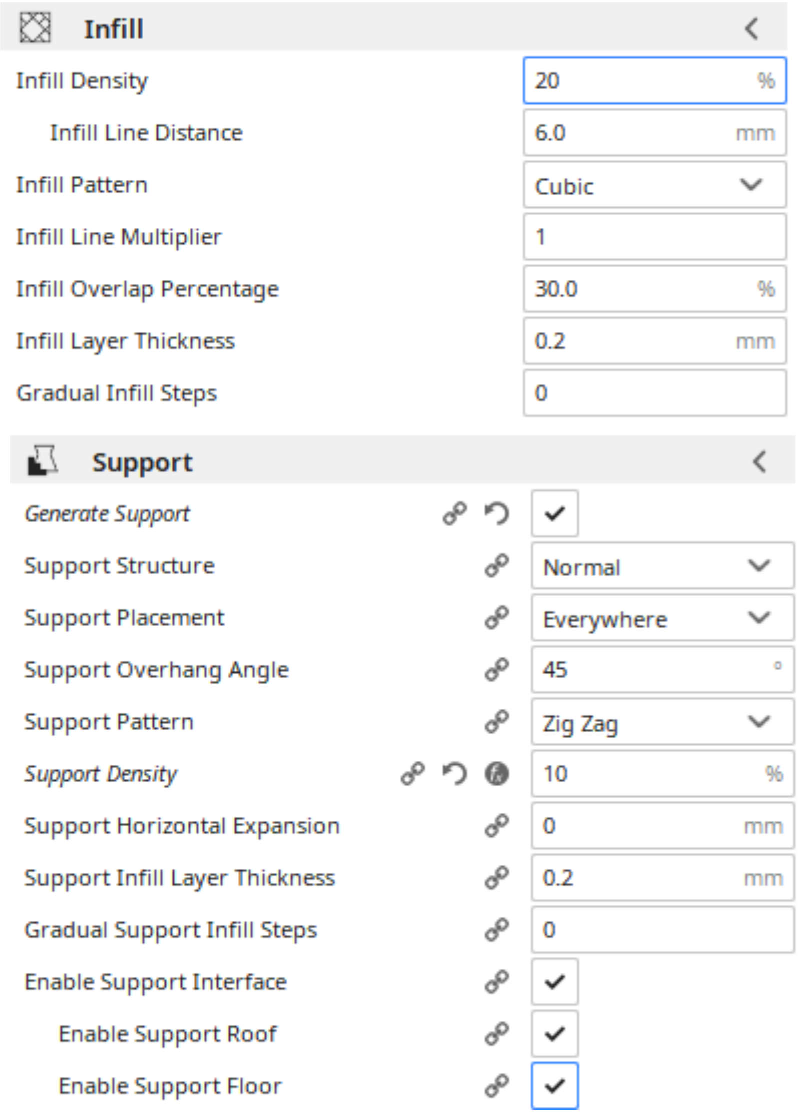


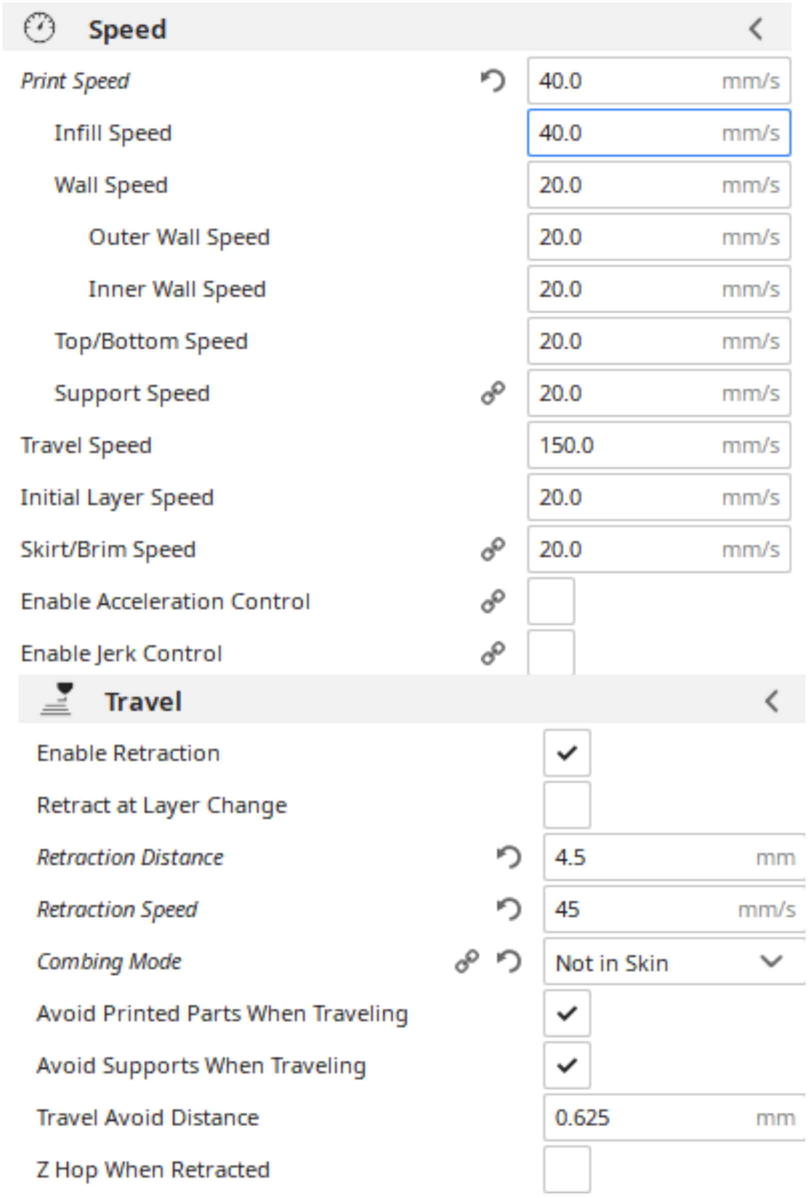


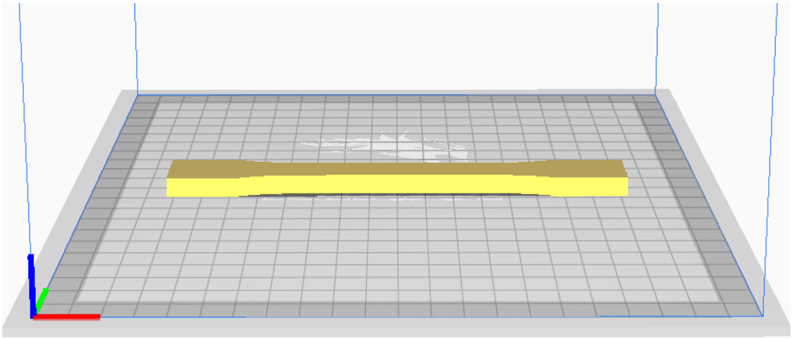
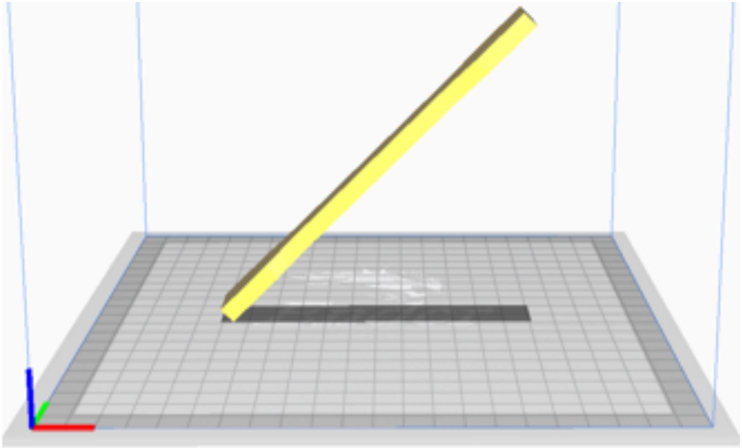
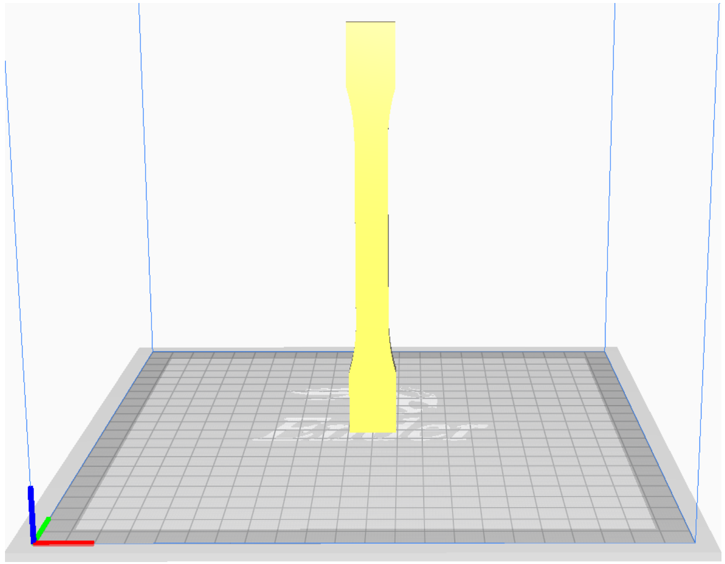
PHASE 1:
CURA 4.7.1 DESIGN

Cura is an open-source slicer made by Ultimaker. It is used to develop G-code for use in different types of additive and subtractive manufacturing machines.

This Cura profile was pre-developed for the Ender 3 Pro and only slight modifications made.



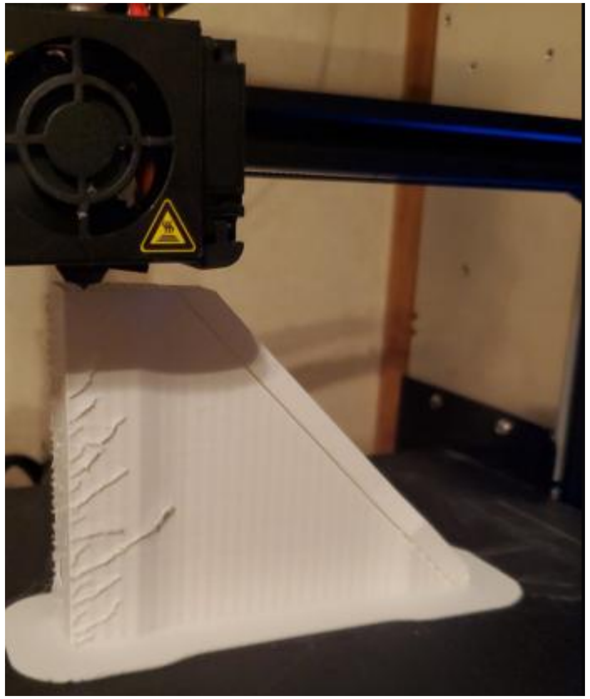


PHASE 1:
CURA 4.7.1

The three orientations in Cura, Cura automatically creates supports based on the settings in the previous slide.

Once the orientation is set you click slice and the G-code is prepared.

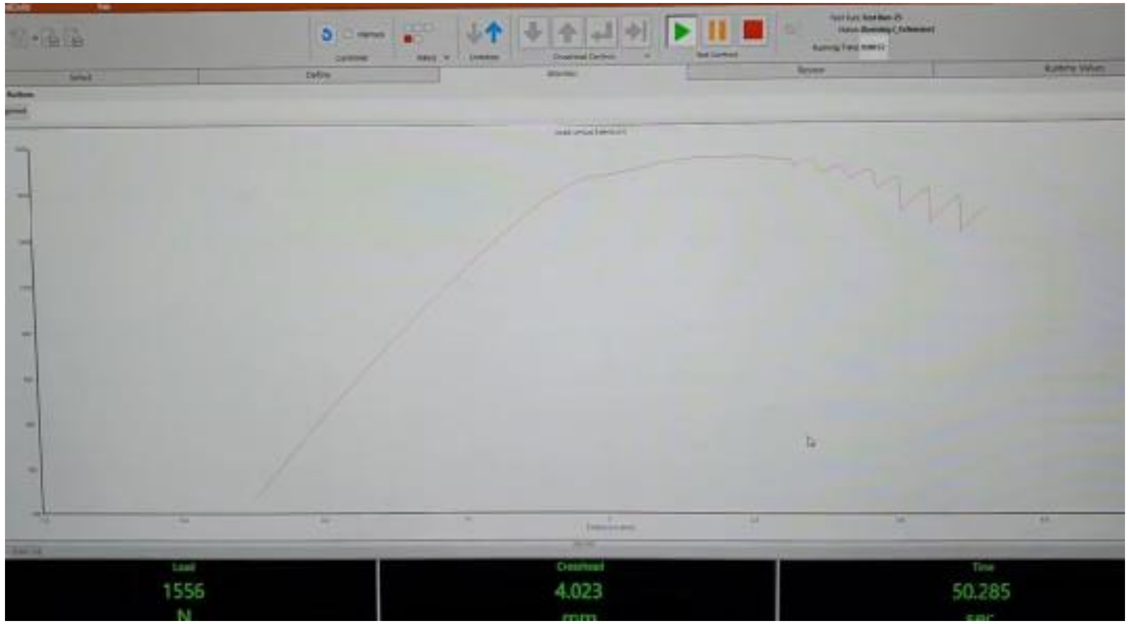


PHASE 2: THE FINAL PRINTS

- After generating the G-Code the prints were made and shown above.
- The prints were marked for tension testing, and in-fills specified.

PHASE 2: TENSION TESTING

- Using the materials testing lab at FSU Panama City, the specimens were tested on the MTS tension testing machine.
- Some errors from this phase could originate from the cylindrical chucks, the initial loading (but this was accounted for) and possible machine errors from not being properly calibrated.



3D Printed Orientation Strength Experiment								
F(N)	F(N) corrected	Area initial (m^2)	L initial (m)	L change (mm)	L change (m)	Stress (Pa) = F/A	Strain = changein L/L	E (Pa) = Stress/strain
5.516728401	0	0.0000884	0.166	0.006074977	6.07498E-06	0	3.65962E-05	0
12.6203413	7.1036129	0.0000884	0.166	0.014234505	1.42345E-05	80357.61199	8.575E-05	937114665.3
19.11977959	13.60305119	0.0000884	0.166	0.022632268	2.26323E-05	153880.6695	0.000136339	1128662446
25.40093613	19.88420773	0.0000884	0.166	0.031149149	3.11491E-05	224934.4765	0.000187645	1198720472
31.8379631	26.3212347	0.0000884	0.166	0.039487353	3.94874E-05	297751.5238	0.000237876	1251710964
38.11982727	32.60309887	0.0000884	0.166	0.047527763	4.75278E-05	368813.3356	0.000286312	1288152648
44.46986008	38.95313168	0.0000884	0.166	0.055687291	5.56873E-05	440646.2859	0.000335466	1313536394
50.55187988	45.03515148	0.0000884	0.166	0.063965941	6.39659E-05	509447.415	0.000385337	1322082806
57.27925491	51.76252651	0.0000884	0.166	0.072304145	7.23041E-05	585548.9424	0.000435567	1344336824
62.93505859	57.41833019	0.0000884	0.166	0.080344551	8.03446E-05	649528.6221	0.000484003	1341992083
68.47856903	62.96184063	0.0000884	0.166	0.08826585	8.82658E-05	712238.0162	0.000531722	1339493260
74.24711609	68.73038769	0.0000884	0.166	0.096246702	9.62467E-05	777493.0734	0.000579799	1340969067
80.85921478	75.34248638	0.0000884	0.166	0.104525345	0.000104525	852290.5699	0.000629671	1353549561
86.8586731	81.34194469	0.0000884	0.166	0.112803988	0.000112804	920157.7454	0.000679542	1354084984
92.72811127	87.21138287	0.0000884	0.166	0.120725286	0.000120725	986554.1048	0.000727261	1356534215
98.21055603	92.69382763	0.0000884	0.166	0.128467902	0.000128468	1048572.711	0.000773903	1354914865
104.356163	98.83943462	0.0000884	0.166	0.136508315	0.000136508	1118093.152	0.000822339	1359649504
110.4155884	104.89886	0.0000884	0.166	0.144727397	0.000144727	1186638.688	0.000871852	1361055516
116.4885788	110.9718504	0.0000884	0.166	0.15300604	0.000153006	1255337.674	0.000921723	1361946587
122.3215408	116.8048124	0.0000884	0.166	0.160986892	0.000160987	1321321.408	0.000969801	1362467158
127.9932327	122.4765043	0.0000884	0.166	0.168789076	0.000168789	1385480.818	0.001016802	1362587087
134.0567474	128.540019	0.0000884	0.166	0.176591246	0.000176591	1454072.614	0.001063803	1366863079
140.1776581	134.6609297	0.0000884	0.166	0.184810342	0.00018481	1523313.684	0.001113315	1368267970
145.7077179	140.1909895	0.0000884	0.166	0.193029424	0.000193029	1585870.922	0.001162828	1363805413
151.5653839	146.0486555	0.0000884	0.166	0.201129398	0.000201129	1652134.112	0.001211623	1363571239
158.0393524	152.522624	0.0000884	0.166	0.208931568	0.000208932	1725369.05	0.001258624	1370837665
162.8984528	157.3817244	0.0000884	0.166	0.216674191	0.000216674	1780336.248	0.001305266	1363964099

PHASE 3: RESULTS ACQUISITION AND ANALYSIS

- This phase consisted of the evaluation of the 11 specimens and compared the material properties in tensile stress.
- As shown the specimens that faired best were the 0-degree specimens.

Total Comparison											
Zero Degree Specimens				90 degree specimens				45 degree specimen			
	Max Stress (MPa)	Max Strain	Modulus E (Gpa)		Max Stress (MPa)	Max Strain	Modulus E (Gpa)		Max Stress (MPa)	Max Strain	Modulus E (Gpa)
Specimen 1	7.27	0.006	1.29	Specimen 6	6.25	0.0059	1.14	Specimen 11	5.53	0.0075	0.84
Specimen 2	14.44	0.013	1.11	Specimen 7	8.17	0.0070	1.33				
Specimen 3	19.57	0.020	0.98	Specimen 8	14.05	0.0096	1.79				
Specimen 4	20.47	0.017	1.20	Specimen 9	19.03	0.0097	2.24				
Specimen 5	24.40	0.014	1.74	Specimen 10	25.63	0.0117	2.59				

DIRECT COMPARISON

SHOWN ABOVE IS A DIRECT COMPARISON OF THE RESULTS ACROSS ALL 11 SPECIMENS

EXPLANATION

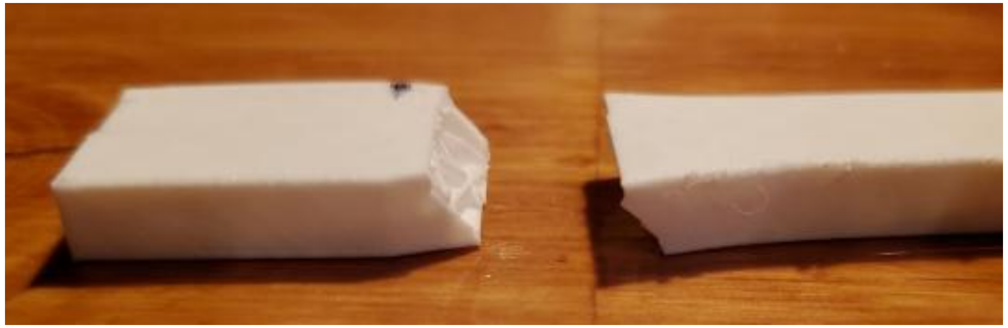
0-Degree specimen

- As shown this specimen did not fail catastrophically
- This may be due to internal micro-structural failures and would not resettle in the tension tester to catastrophically fail.

90-Degree specimen

- This specimen did fail catastrophically along the layer line

THE 45-DEGREE SPECIMEN



- Initially I believed this would be the stronger out of 90 and 45
- This failed at a lower stress in the round
- It may be due to internal micro-failure at this location
- Or initial loading caused a slight stress concentration that caused failure at the round near the chucks
- This was the weakest of the specimens

CONCLUSION

IS ORIENTATION IMPORTANT

According to the data, the orientation of loaded prints is important to consider as the 0-degree specimens Performed the best.

The 90-degree specimens did not do much worse but if it is an important application then it is worth the time to consider orientation.

The 45-degree specimens results were surprising and would be worth to check with another specimen.

Possible errors include, my measurements, printing defects, my calculations, using a cylindrical chuck.

REFERENCES

GUTIERREZ, R. J. G. (2020, JANUARY 11). PLA PLASTIC/MATERIAL: ALL YOU NEED TO KNOW IN 2020. ALL3DP. HTTPS://ALL3DP.COM/1/PLA-PLASTIC-MATERIAL-POLYLACTIC-ACID/

ASTM D638-03 – SOURCED 11/20/2020

REDWOOD, B., SCHÖFFER, F., & GARRET, B. (2017). *THE 3D PRINTING HANDBOOK: TECHNOLOGIES, DESIGN AND APPLICATIONS* (1ST ED.). 3D HUBS.

CALLISTER, WILLIAM D., AND DAVID G. RETHWISCH. MATERIALS SCIENCE AND ENGINEERING. 9TH EDITION, JOHN WILEY & SONS INC, 2013.

QUESTIONS?