Portland State University

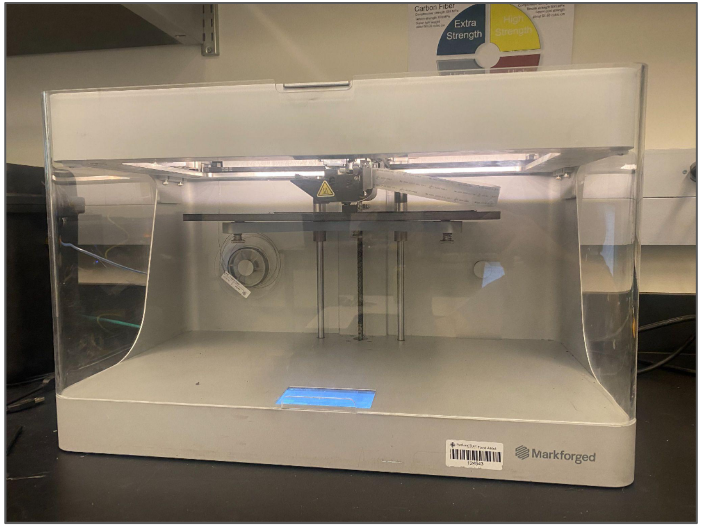
Material Testing of Additively Manufactured Onyx Filament

Jason Miranda, Alexander Hunt and Jonathon Tran
Agile and Adaptive Robotics Lab of Portland State University, Portland Oregon

What is Additive Manufacturing?

- Layer by layer building of 3D parts
- Has weaker material properties compared to other processes

How does this relate to our experiment you might ask?

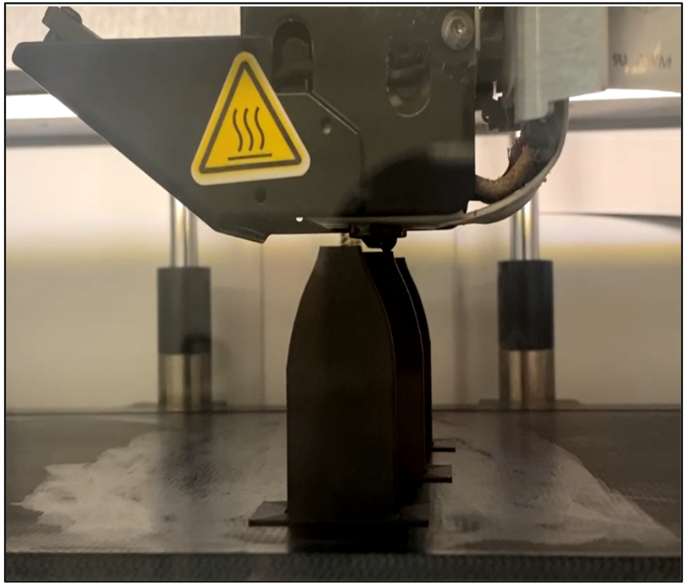


Fused Filament Fabrication / Fused Deposition Modeling

What is Fused Filament Fabrication?

How does it work?

This process is important because allows quick and inexpensive prototyping of a product but is quite porous and typically weaker than other methods

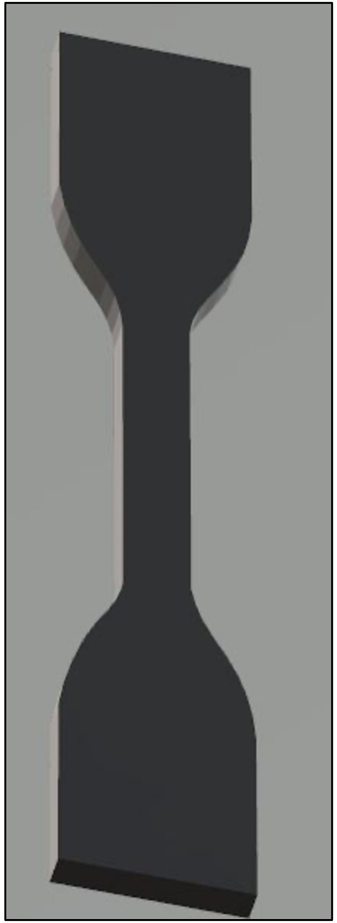


3D CAD Modeling -> STL File

This process of designing using a 3D CAD was not used specifically in this experiment due to using a standardized specimen but is essential to the 3D printing process

- Programs used like solidworks or Tinkercad

- Computer aided design shows surfaces by a series of triangles



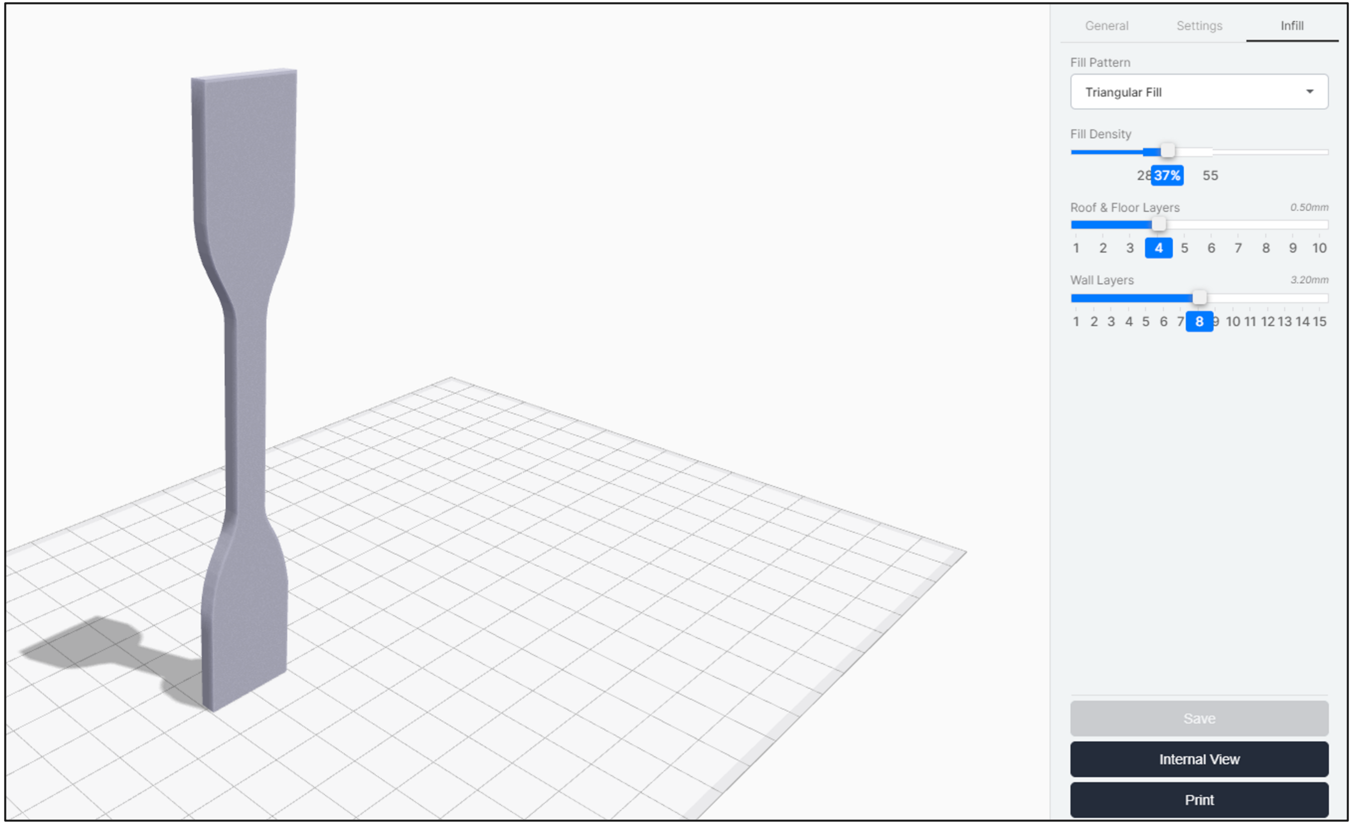
Cloud Slicing and 3D Printing with The Mark Two

Once you have an STL file you can start the process known as part slicing. Our printer has a proprietary software called Eiger.io that has settings that change the product Attributes such as

- Infill
- Wall Layers
- Roof & Floor Layers

3D Printed Specimen in Eiger.io

Once the settings are chosen print button is clicked and the software sends the file into the cloud where the STL file is sliced and turned into a pathway for the printer to follow.



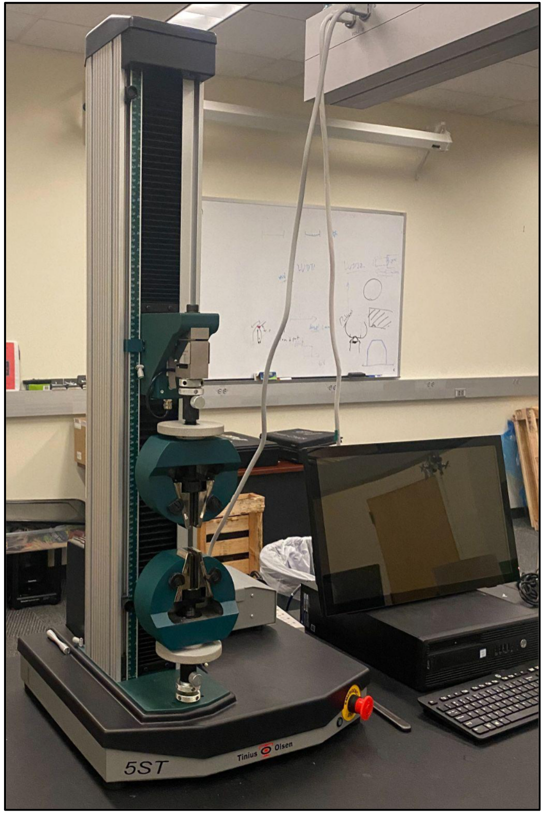
Mechanical Tensile Testing

Tensile testing is important measure of a materials strength and flexibility. It is used in incredibly important aspects of engineering like bridge building.

Tinius Olsen 5ST:

- Vice Grip hands pull the specimen

- Captures Force & Position in real time



Young's Modulus

Young's modulus named after Thomas Young, a British scientist of the 19th century; measures how much a object can stretch before it permanently deforms. The higher value of the modulus the stiffer the material is.

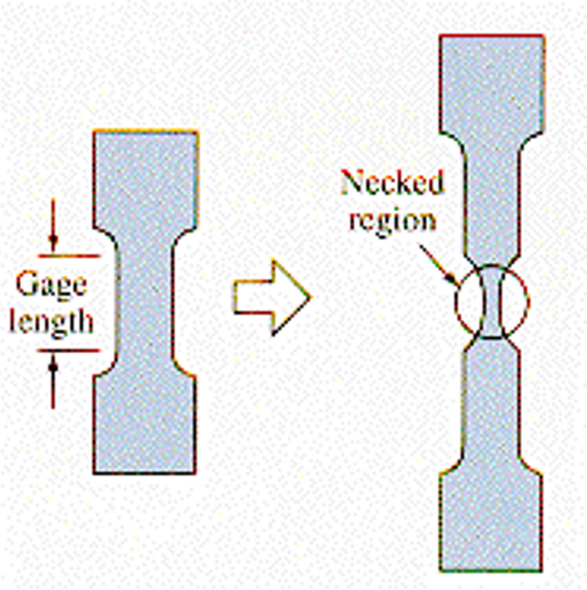
An example of this is steel vs copper

Steel has a modulus of 190 GPa Meanwhile Copper has a modulus of 160GPa. This means that if you were to bend each metal, copper would move farther while still able to bounce back to its original shape.

Yield Strength

The yield strength is the point at which the material is permanently deformed and if force was released it would not return back to its original form.

In our experiment is seen where force is applied and it is the point where movement is detected, this diagram shows the permanent deformation before fractured called “necking”



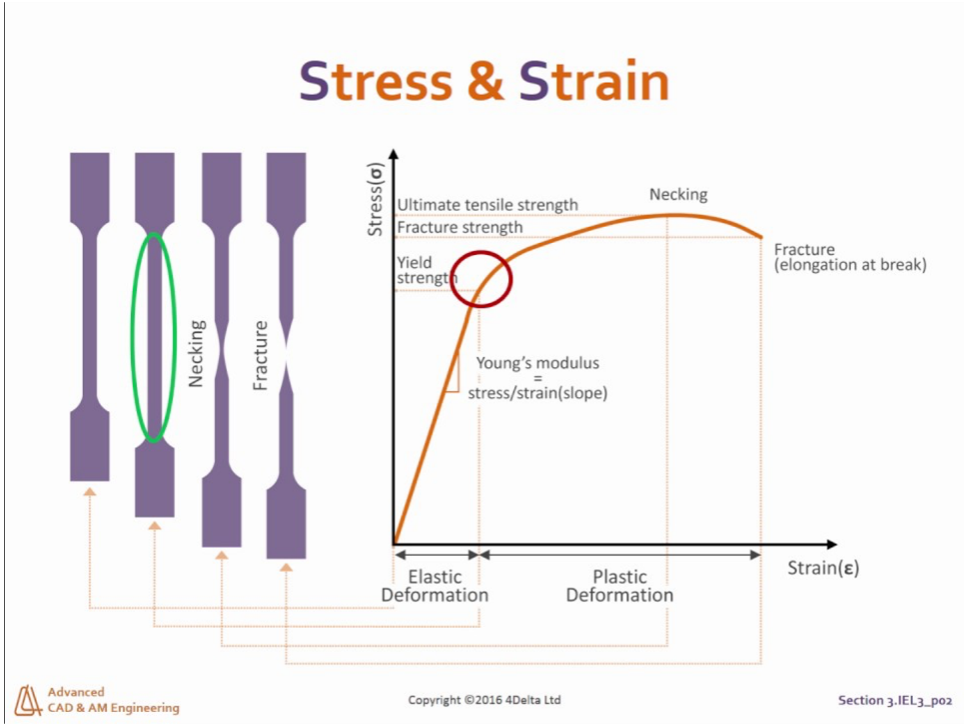
Source: Google Images
Standardized specimen displaying necking

Ultimate Strength

Ultimate strength is the maximum amount of force the specimen can withstand throughout the whole experiment.

As the specimen is under stress it experiences elastic deformation where it would bounce back to its original shape if the stress was released.

Yield strength is the point at which elastic deformation turns into permanent plastic deformation, causing necking before the fracture happens.



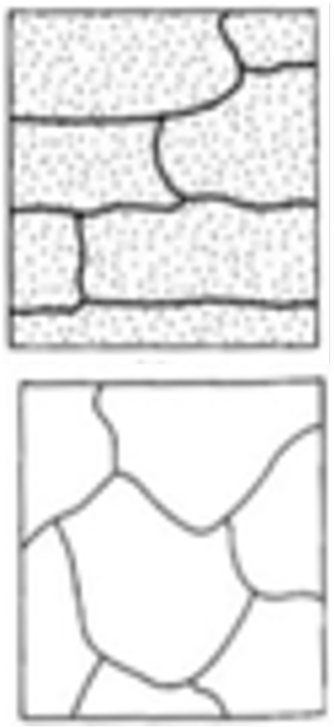
Source: Google Images

Annealing

Process: The material is heated at its glass transition temperature where it is in a state between solid and liquid. Next material is allowed to cool slowly allowing the internal stresses within the material to release and crystalize more even and smooth.

- Used Commonly in metals to increase ductility but still retains toughness

- The process alters the microscopic structure of the metal to make it more even



Source: Google Images
Microstructure before (top) and after annealing (bottom).

Our Method For Annealing

The biggest hurdle for our research was finding the correct glass transition temperature for our specific filament. The Onyx material that our Mark Two printer uses is a proprietary blend advertised as a "micro carbon fiber filled nylon".

Following the thesis of Anthony G. Tantilio where he annealed Nylon 6 3D printed specimens we used the low end of his experiment of 140 ℃. Our high end was 235 ℃ which was the temperature the printer extrudes the molten material. So we decided to anneal our specimen at 180 ℃ which was about the middle point between the two numbers

Results of Wall layer settings

Our initial expectation was to see an increase in strength as the wall thickness increased. The data agrees to an extent, it has an obvious increase between wall layer thickness setting 2 and 4.

We think the cause of the decrease is general fluctuation in the data. We expect with a bigger dataset that the data would flatten after wall thickness setting 4.

This is because the layer gaps become visibly indistinguishable after setting 2 due to the specimen being too thin to see a change in the larger wall thicknesses.

Also it seemed to be that each batch of printed specimens seemed to have different properties and inconsistencies.

Wall Layer Setting	Young's Modulus (MPa)	Ultimate Strength (N)	Yield Strength (MPa)
2	38.48	417.6	19.31
4	57.9	524.6	24.42
6	67.31	543.1	25.1
8	65.96	570.2	26.2
10	60.61	512.3	23.45

2 4 6 8 10

Results of Annealing Specimens

The data shows an average decrease of 10% for ultimate strength and a decrease of 3% of yield strength. The most significant change in the materials properties is the young's modulus. For wall layer 8 setting the material becomes 60% more brittle than before annealing and for wall layer 4 it becomes 158% more brittle than before annealing.

Some causes for this data is that we were not able to reach the glass temperature which would heat treat the material. This conclusion makes sense because items heat treated tend to be more brittle; And we would expect to see at the fracture site a smooth finished side but the annealed side (left) still have visible layer lines, but compared to the non-annealed (right) there are many voids that have been closed

Wall Layer Setting	Young's Modulus (MPa)	Ultimate Strength (N)	Yield Strength (MPa)
8 Not Annealed	65.96	570.2	26.2
8 Annealed	106	527	24.66
4 Not Annealed	57.9	524.6	24.42
4 Annealed	205.42	455.08	27.7

Conclusions From the Experiment

The downside to additive manufacturing is that parts tend to be weaker than typical manufacturing processes. The experiment has shown that some extra strength can be added to materials via changing slicer settings.

More research is needed to determine the proper way to anneal the onyx material but it has been shown that the process of annealing can reduce the porous structure of the material.

Each batch of printed material have different material properties that could be related to ambient temperature and humidity that could use testing to reduce the variability in the data

Acknowledgements / Q&A

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