3D Printing: An Overview

RPI STEAMM Inventor's Studio Summer Program
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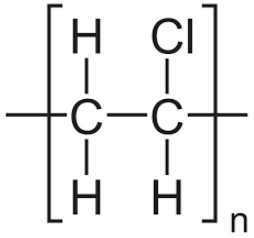
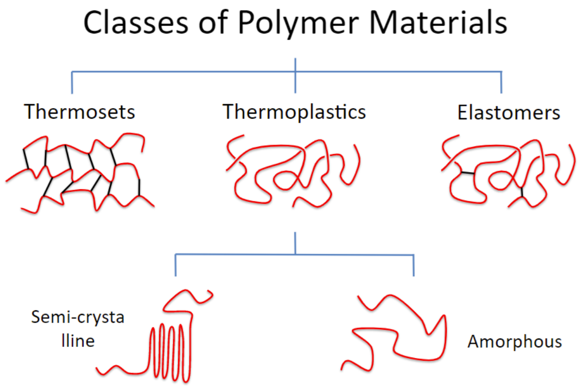
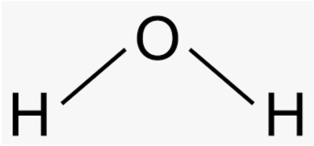
Recap – Polymer Chemistry

- Polymers exist of repeating subunits made up of atoms bonded together
- 3 polymer classes: thermoset, thermoplastic, elastomer
- Basic molecules like water, carbon dioxide, or oxygen gas look MUCH different:

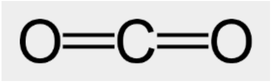


Polyvinyl Chloride (PVC)





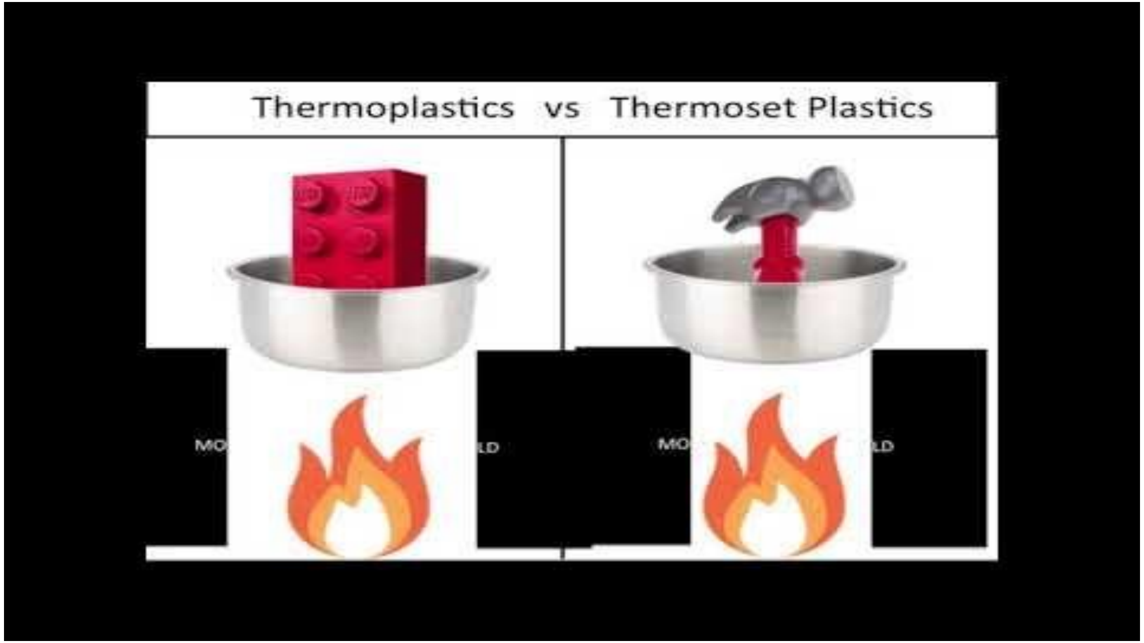
Water (H_2O)



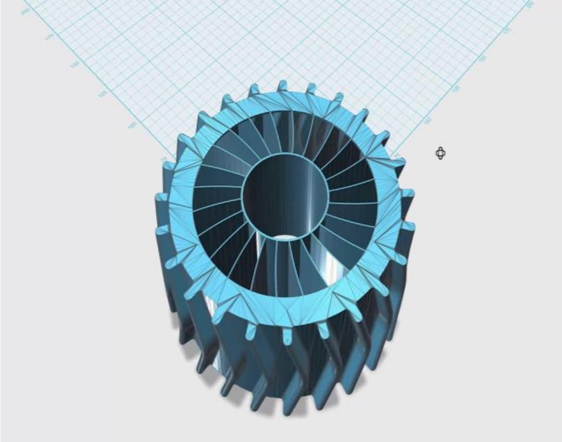
Carbon Dioxide (CO_2)

Oxygen Gas (O_2)

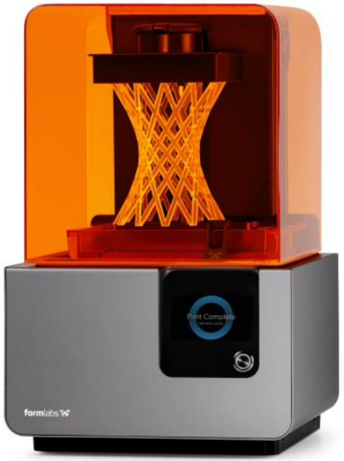
Thermoplastics vs Thermosets



3D Printing Overview - Recap



- Method of manufacturing commonly called Additive Manufacturing (AM)
- Based off of a CAD drawing (Computer-aided design)
- CAD drawing converted to a digital file that can relay instructions to the 3D printer

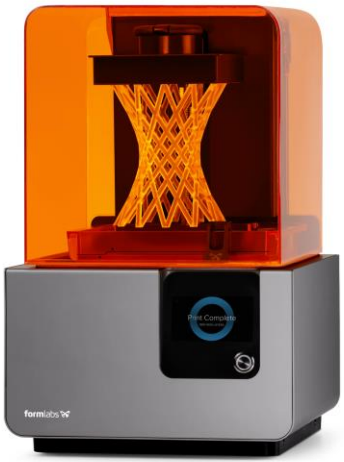


3D Printing Overview

- Several methods of 3D printing exist. Here are just four examples:
  - Fused Deposition Modeling (FDM)
  - Selective Laser Sintering (SLS)
  - Stereolithography (SLA)
  - Digital Light Processing (DLP)

FDM

SLS

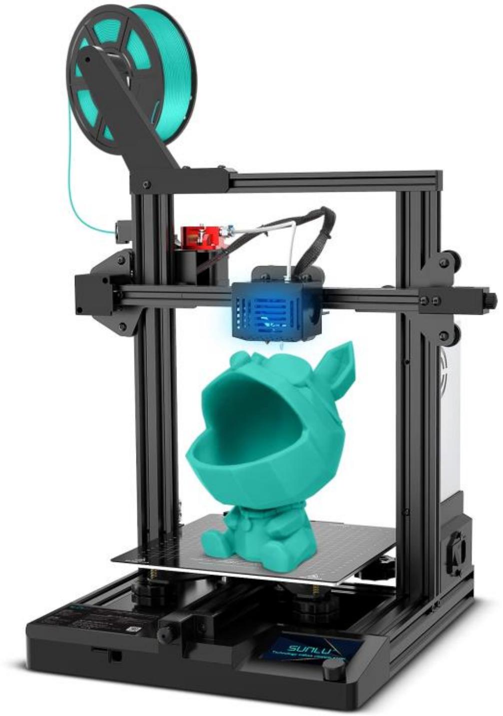


SLA

DLP

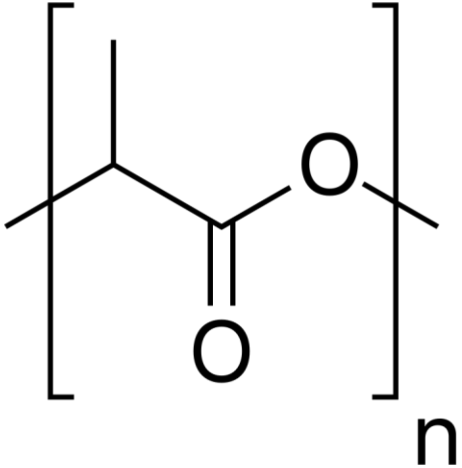
FDM 3D Printing

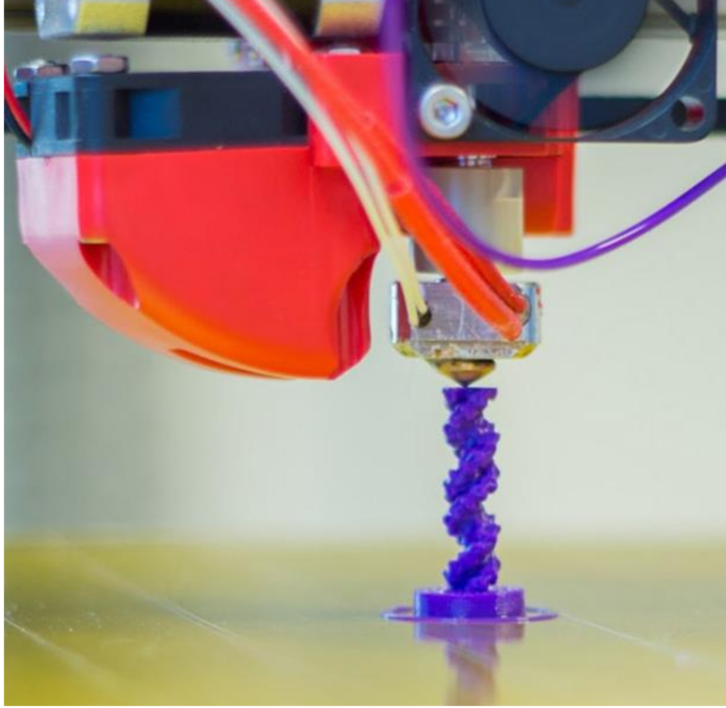
- Fused deposition modeling (FDM) is a process that melts solid plastic into liquid polymer and uses it to trace out the desired 3D object, layer-by-layer
- Quick method typically used to create prototypes and small models



PLA

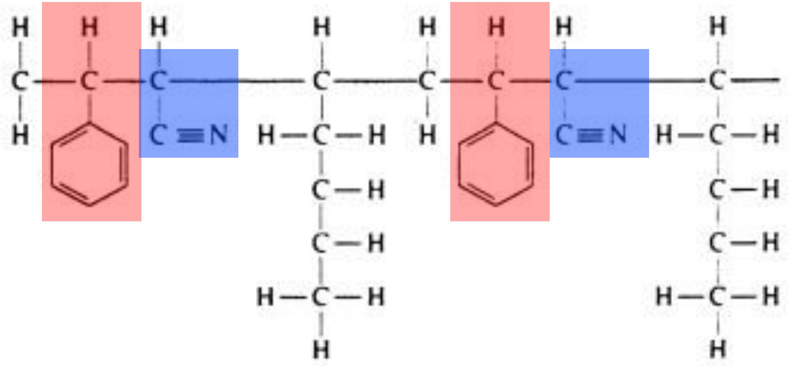
- Poly(lactic Acid), referred to as PLA, is one of the most popular 3D printing plastics
- It is thermoplastic polyester polymer that can be melted down and deposited in layers to synthesize specific objects





ABS

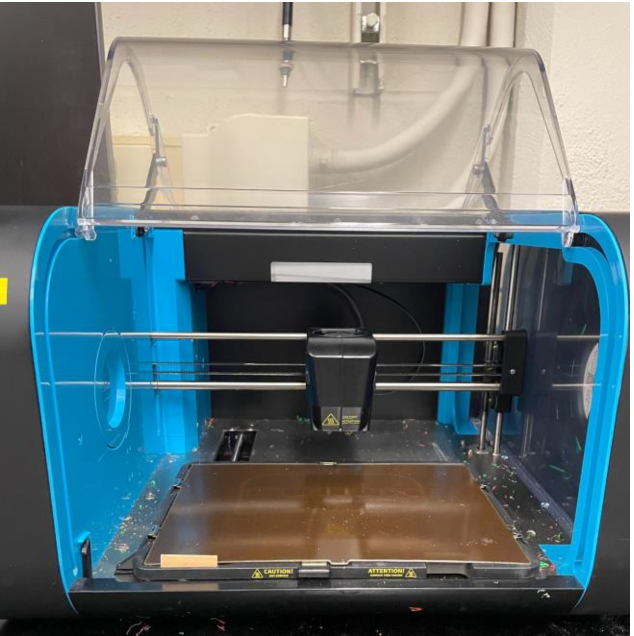
- Acrylonitrile butadiene styrene (ABS) is another very common 3D printing material
- It is also a thermoplastic polymer, containing styrene and acrylonitrile

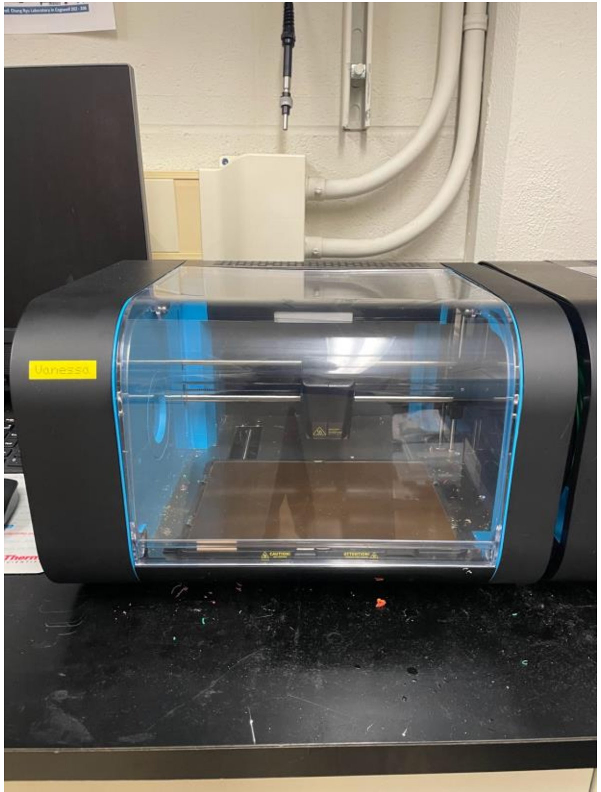


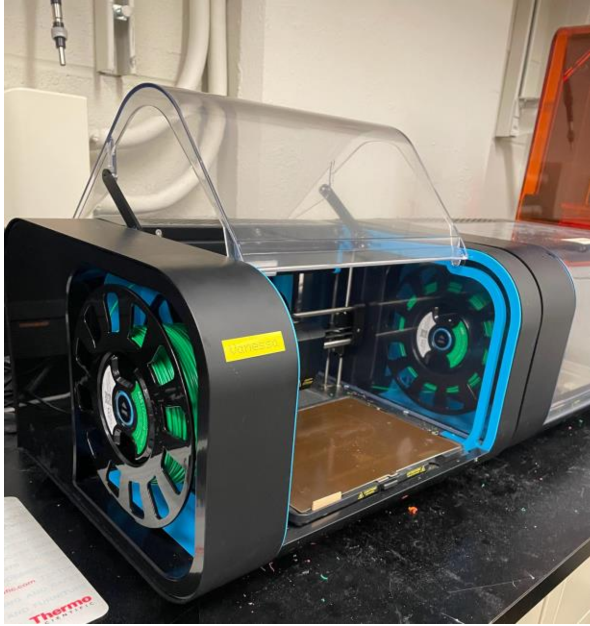
FDM 3D Printing – PLA vs ABS Filaments

FDM 3D Printing

In-Lab FDM Printer







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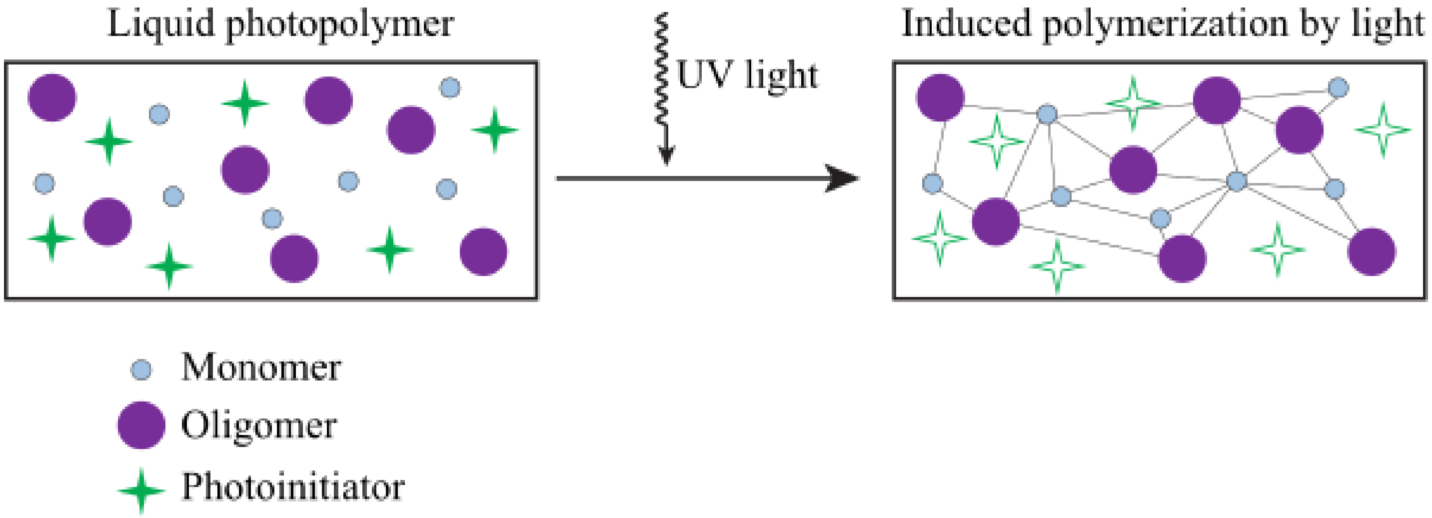
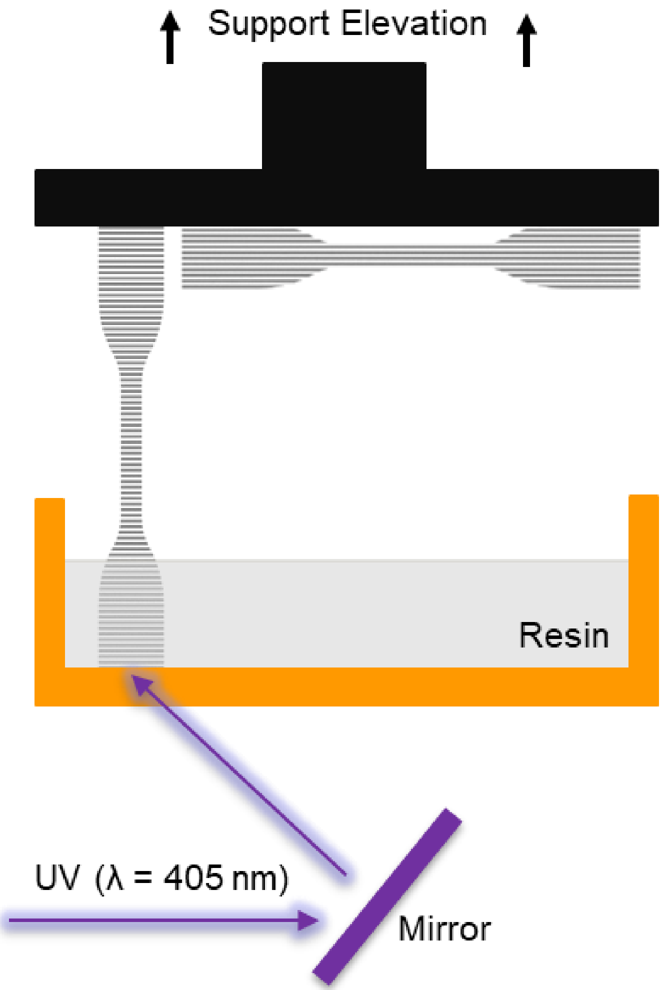
SLA 3D Printing

- Stereolithography (SLA) is a process that utilizes a photopolymer and a light source (usually UV) to shape a 3D object, layer-by-layer
- The UV light induces a chemical reaction called *photopolymerization*
- Creates a smooth and detailed object with very high resolution

Photopolymerization

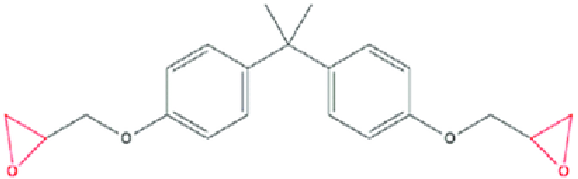
- Polymerization which occurs from the absorption of light (typically in the UV range)
- Curing: Another word for polymerization

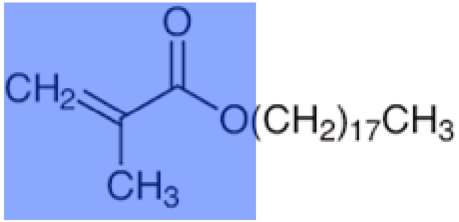



Support Elevation
Resin
UV (λ = 405 nm)
Mirror

SLA Polymers

- Liquids used for SLA are known as photopolymer resins
- Photopolymer resins are able to polymerize when exposed to UV light
    - They contain some fraction of photoinitiator which absorbs UV light
- These photopolymers are often comprised of epoxides or (meth)acrylate functional groups
    - Once photoinitiator molecules absorb UV, they activate these functional groups which then react with one another to form polymer chains!

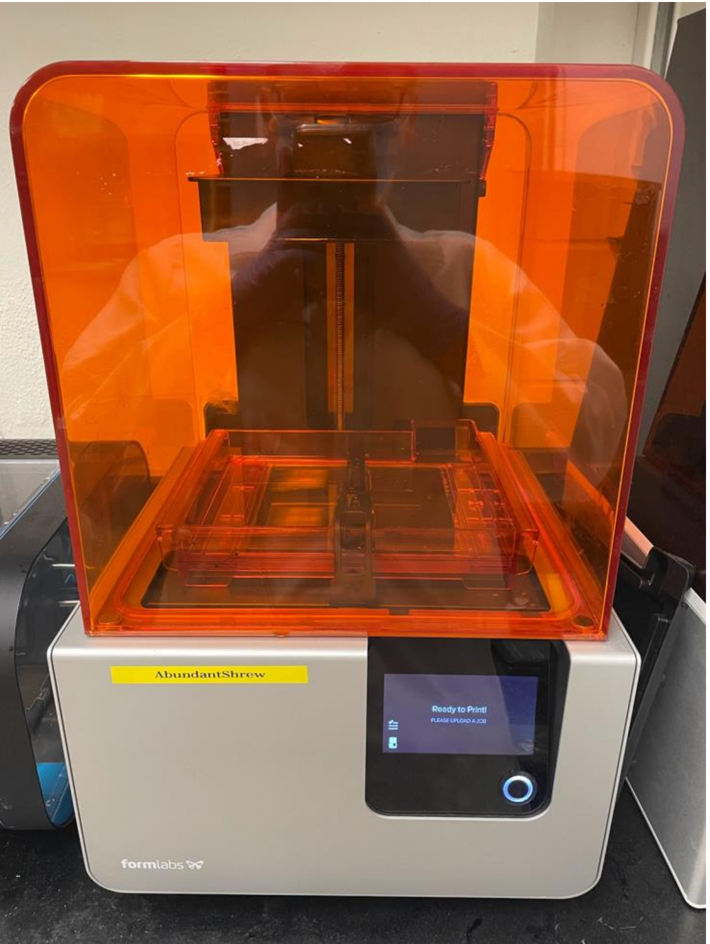


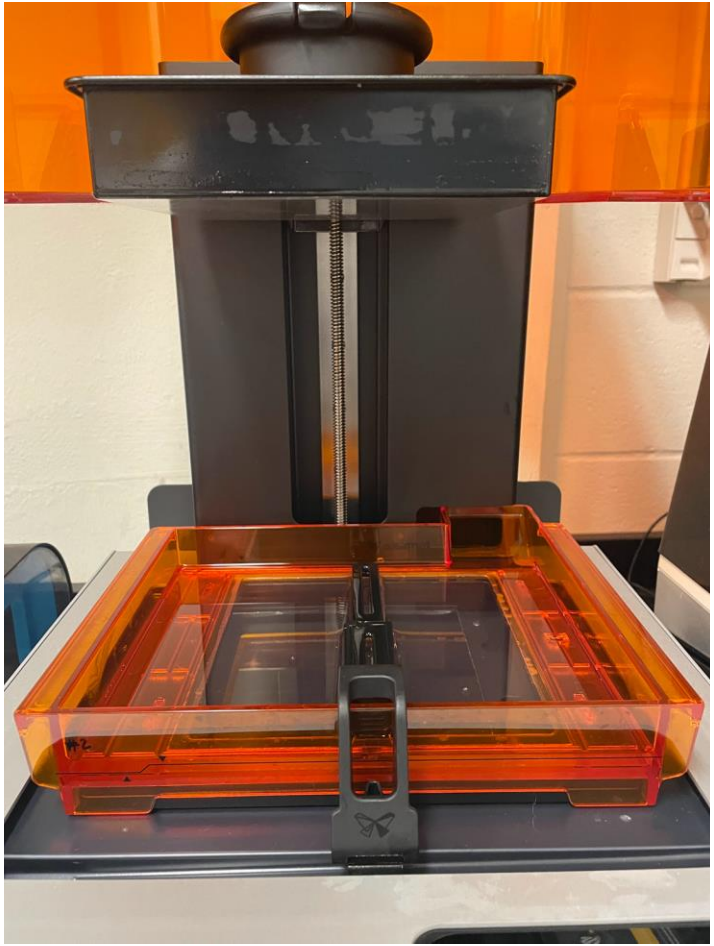


SLA Printing Process

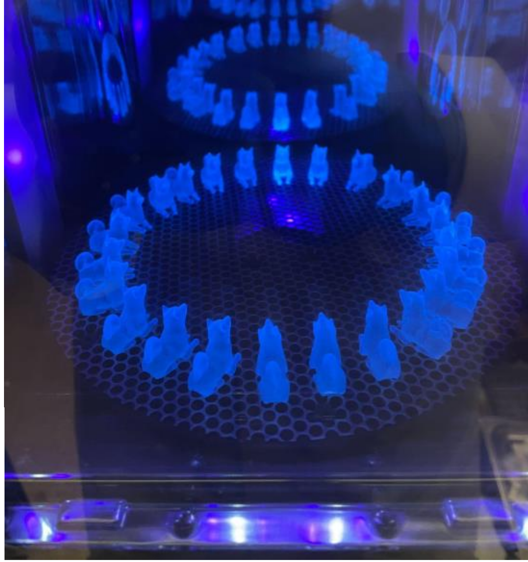
SLA Printing Process

In-Lab SLA Printer

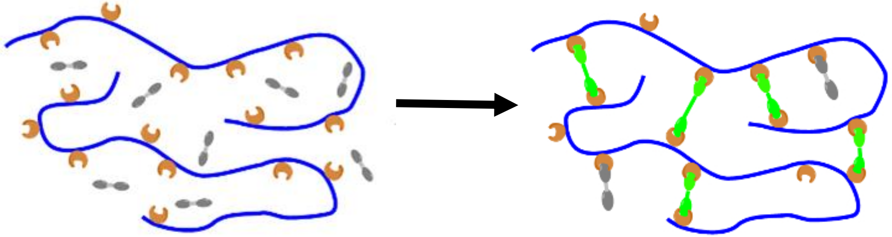




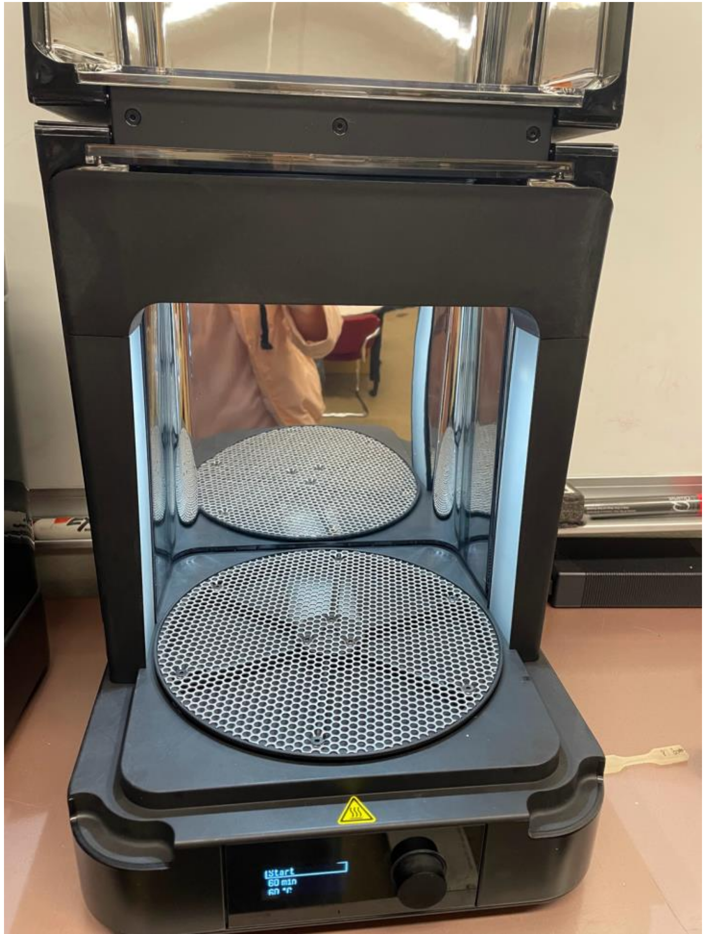
Post-Curing (Crosslinking)



- Crosslinking: The process of further polymerization between polymer chains
  - This happens due to the presence of reactive functional groups within the chains
- Additional UV light (post-curing) after initial photopolymerization causes crosslinking to occur
  - Crosslinking causes the resin to harden because the chemical structure becomes more rigid
- Objects are post-cured in order to improve their physical properties
  - Removes any uncured monomer
  - Improves tensile strength
  - Removes stickiness



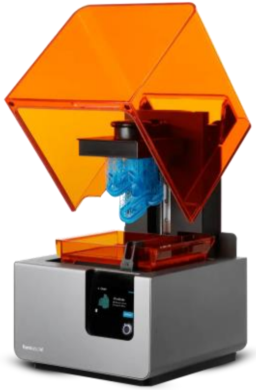
In-Lab Post Curing Chamber



SLA vs FDM

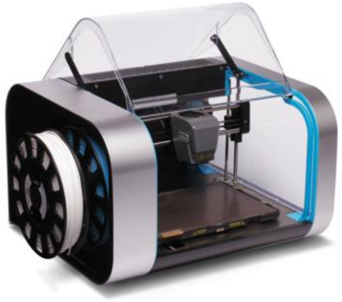
SLA (Stereolithography)

- Uses a **liquid** resin
- Material is a photopolymer
- Builds each layer using UV light photopolymerization
- More expensive
- Thin layers, leading to an increase in quality



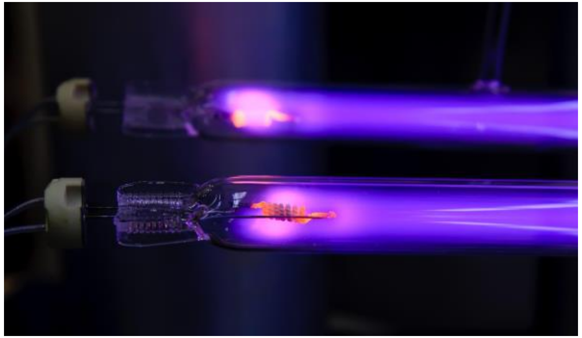
FDM (Fused Deposition Modeling)

- Uses a **solid** plastic
- Material is a thermoplastic polymer (can melt)
- Builds each layer by depositing melted plastic which cools and hardens
- Less expensive
- Thick layers, leading to decreased quality



Review!

Take 5-10 minutes to identify if each object is associated with SLA or FDM



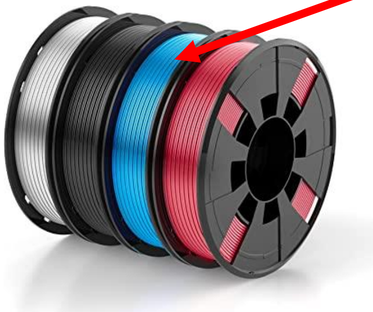
#3DBenchy made on a formlabs Form 2 SLA 3D printer (3DBenchy.com)

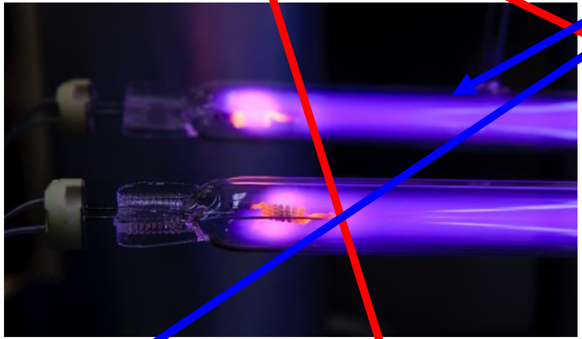
Review!

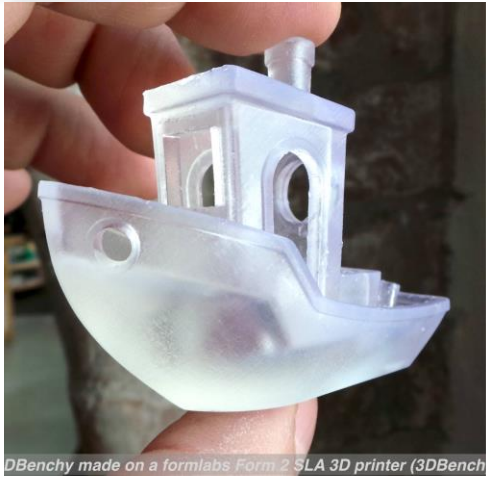
FDM

SLA

Take 5-10 minutes to identify if each object is associated with SLA or FDM

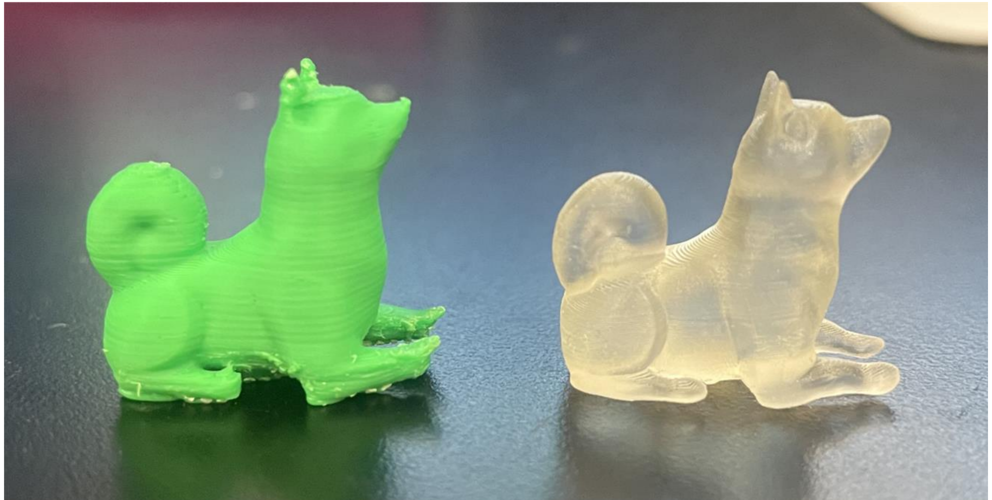






FDM vs SLA

Take a look at these 3D printed dog samples!



Stress and Strain

- Stress and Strain are important mechanical properties
- Stress: The force applied to an object divided by the area
  - Measured in Pascals (Pa) or Pounds Per Square Inch (PSI)
- Strain:The deformation (change in length) of an object in proportion to the original length

$$\sigma = \frac{F}{A}$$

where

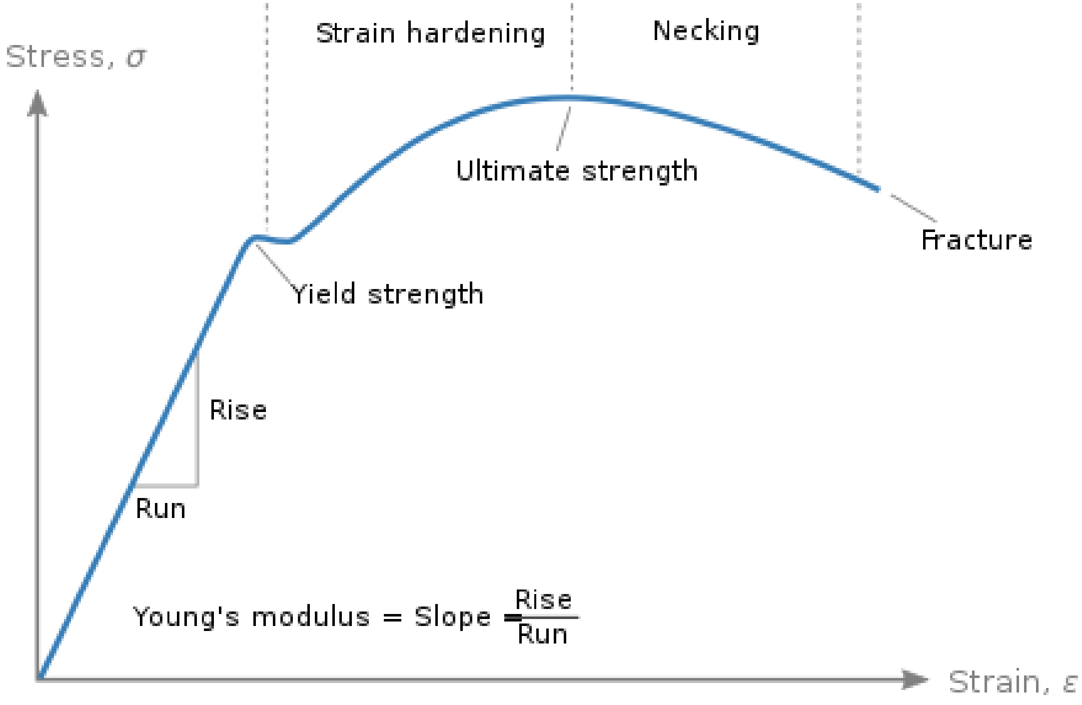
- σ stress [Pa]
- F applied force [N]
- A cross-sectional area [m^2]

$$\varepsilon = \frac{\Delta L}{L_0}$$

where

- ε strain
- ΔL total elongation [m]
- L_0 original length [m]

Stress Strain Curve



- Yield Strength: The maximum stress that can be applied before permanent deformation
- Ultimate Strength: The maximum stress a that can be applied before something breaks
- Necking: A decrease in area when stress applied exceeds ultimate stress

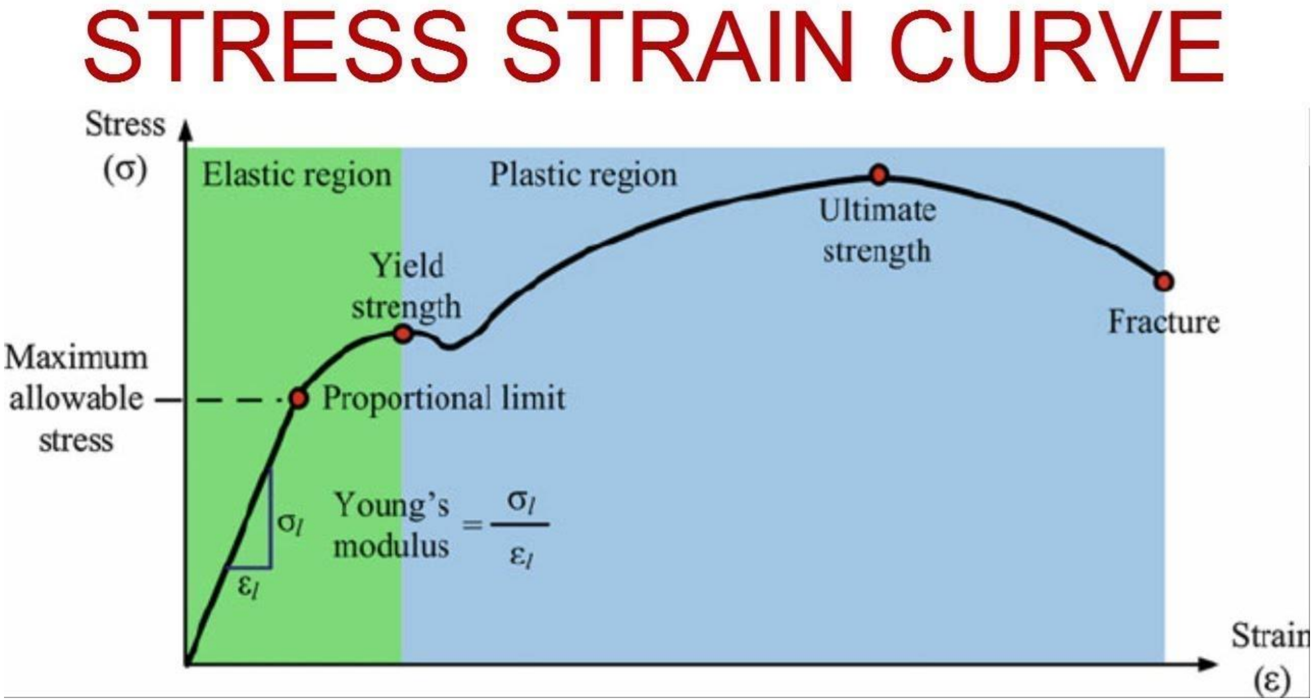
Young’s Modulus

- A measure of elasticity
- The ratio of the stress vs the strain in the elastic region

$$E = \frac{\sigma}{\varepsilon} = \frac{\text{stress}}{\text{strain}}$$

E ⟶	Young’s Modulus (Elasicity)
σ ⟶	stress
ε ⟶	strain

Elastic and Plastic Regions

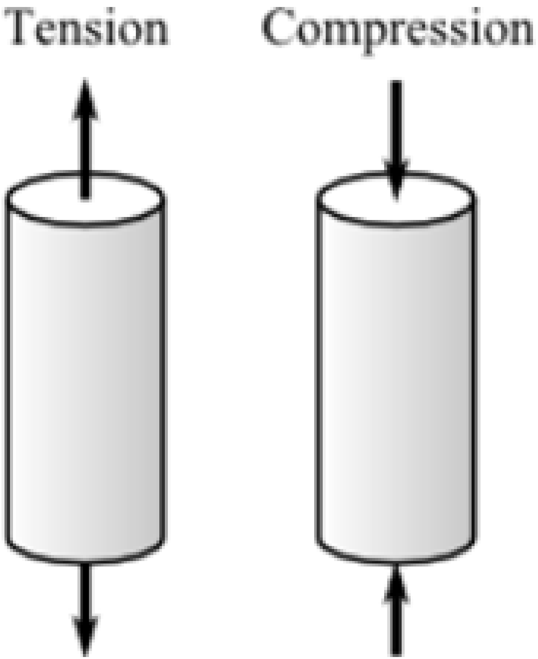


- Elastic Region: Deformation IS NOT permanent
- Plastic Region: Deformation IS permanent

Deformation Observation

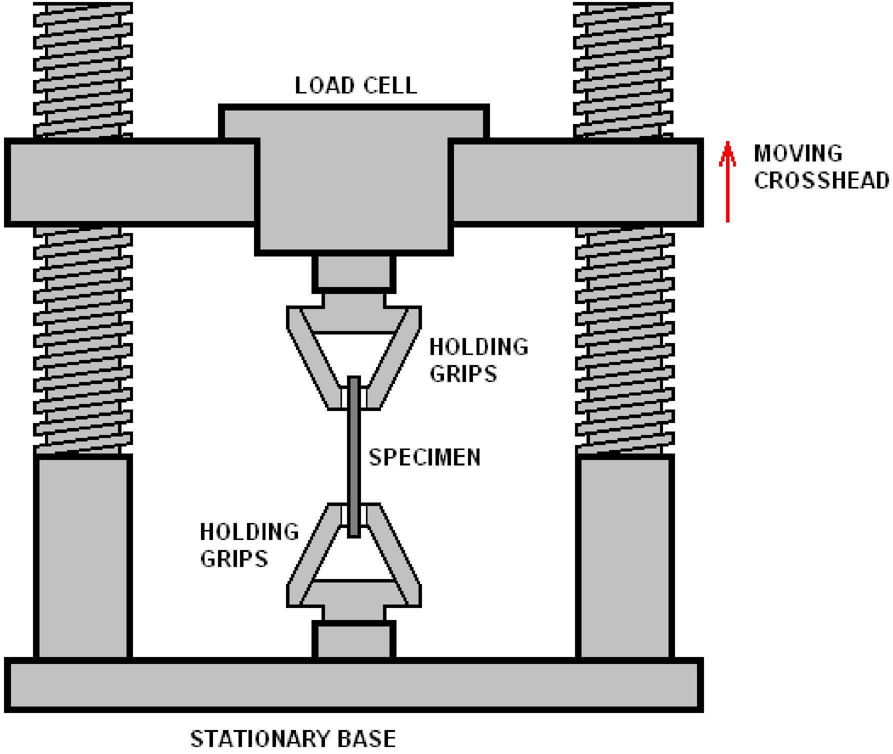
Tension and Compression

- Tension: Force is applied outwards
- Compression: Force is applied inwards



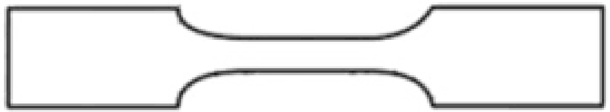
Tensile Test

- Clasps onto each end of a specimen and pulls them, applying tensile force
- The machine can calculate the stress and strain
- Information about strength and elasticity can be gathered

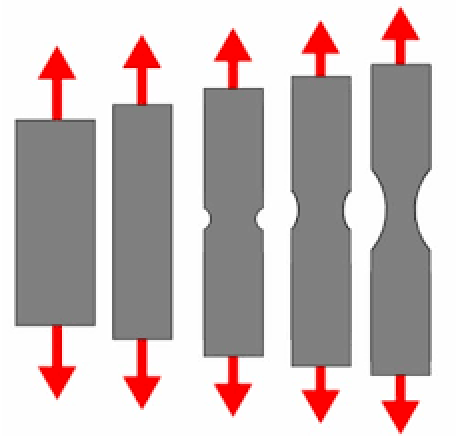


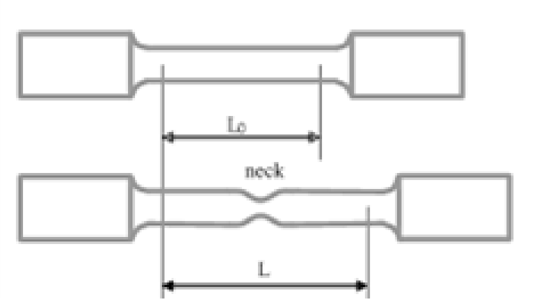
Tensile Test Samples

“Dogbone” Sample



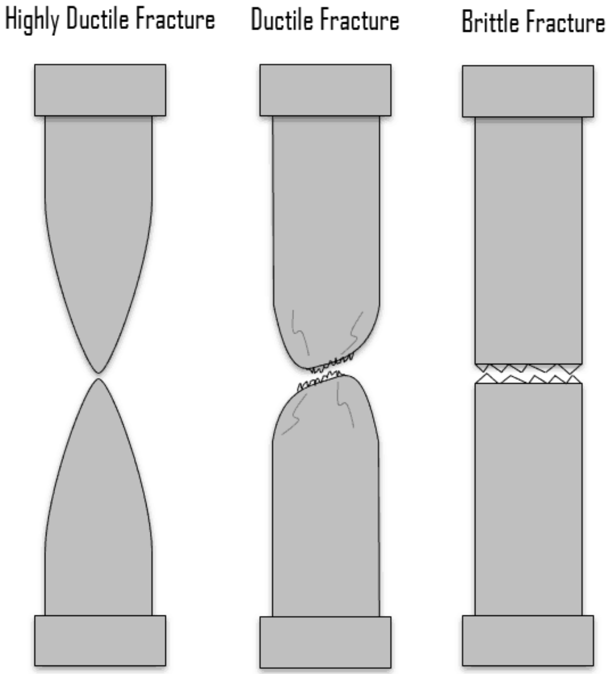
Straight Sample

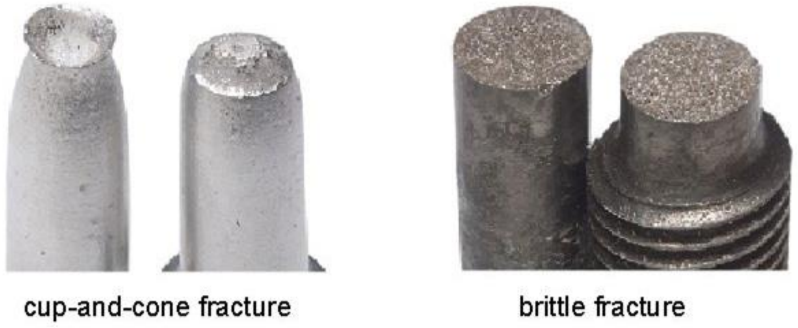




Ductile vs Brittle

- Ductile: Easily stretched, has high elasticity, slower deformation, lots of necking before fracture
- Brittle: Does not stretch easily, deformation is not visible before fracture occurs, harder to tell when it will break





Adapted from Fig. 8.3, *Callister 7e.*

Review!

Which image below has ductile fracture and which has brittle fracture?

1.

2.

Review!

Which image below has ductile fracture and which has brittle fracture?

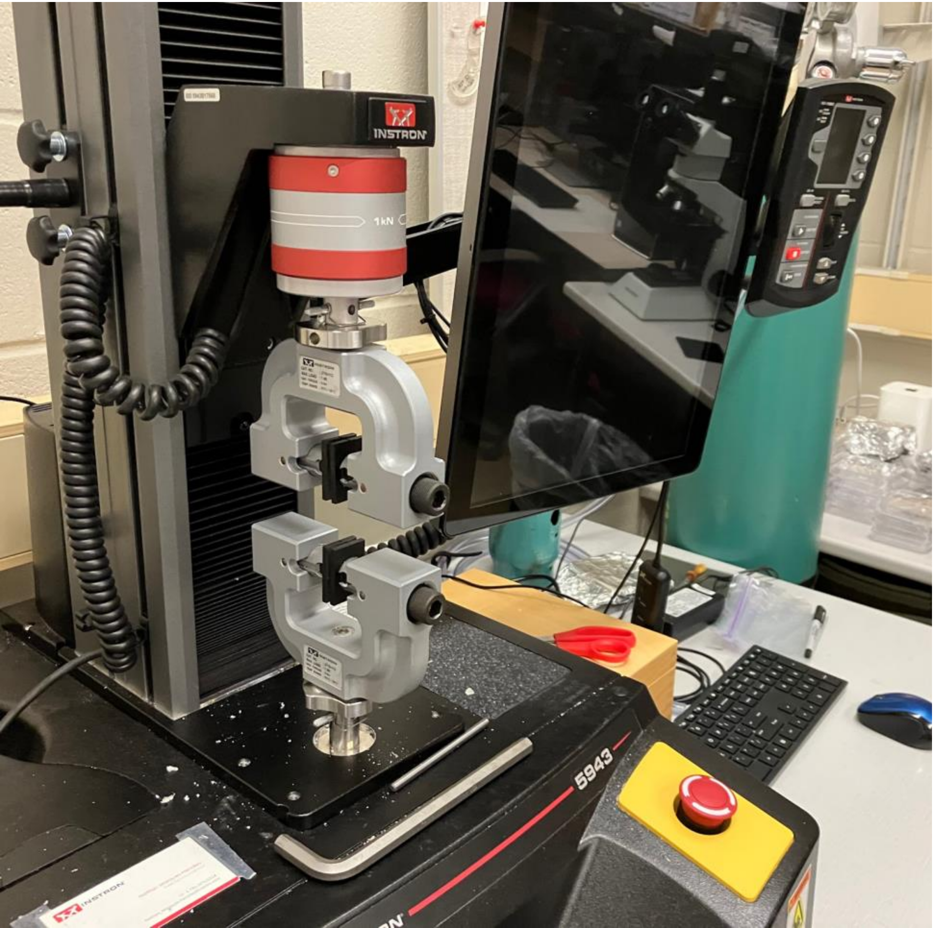
1.

Brittle Fracture

2.

Ductile Fracture

Instron in the Lab

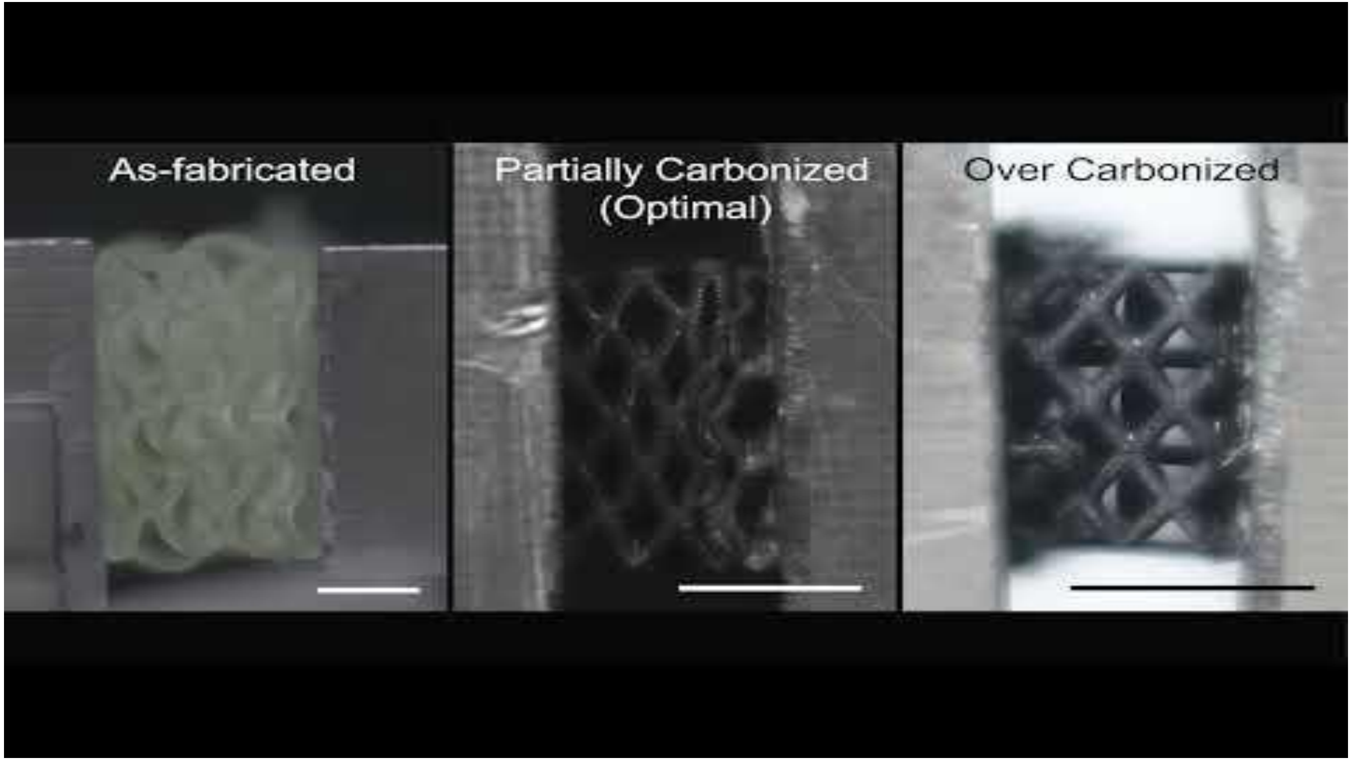


Tensile Test Video 1

Tensile Test Video 2

Tensile Test Video 3

Compressive Test on 3D Printed Material



Shape Memory 3D Printed Polymer Material

World's Largest 3D Printer

Questions?