



# Additive Manufacturing and Characterization of Polylactic Acid (PLA) Composites Containing Metal Reinforcements

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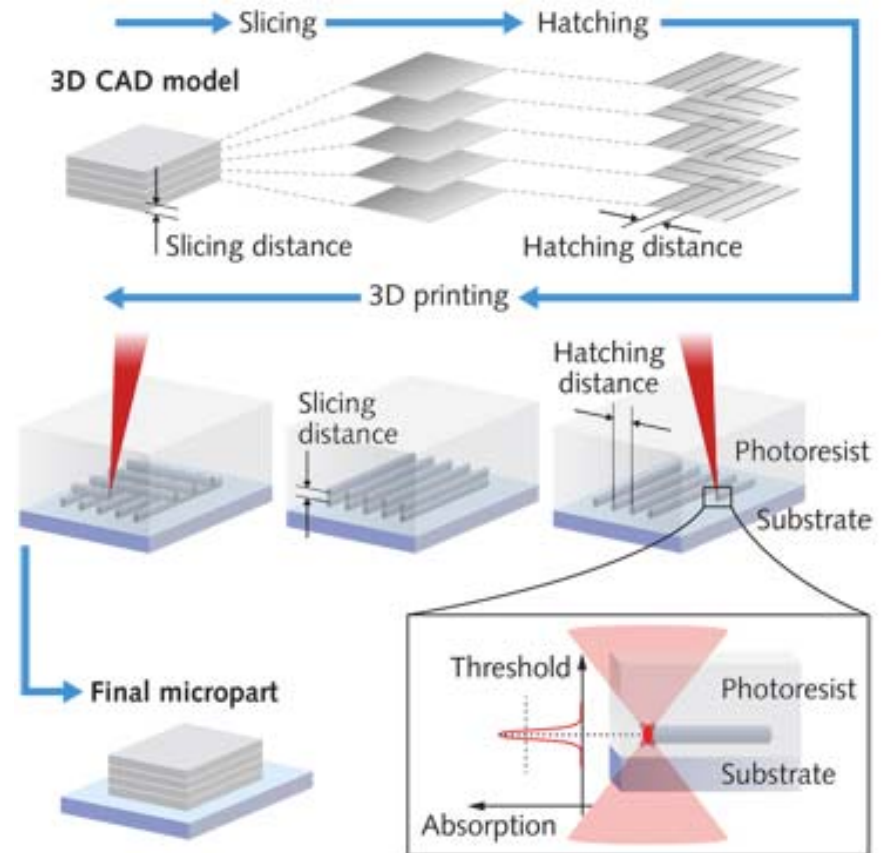
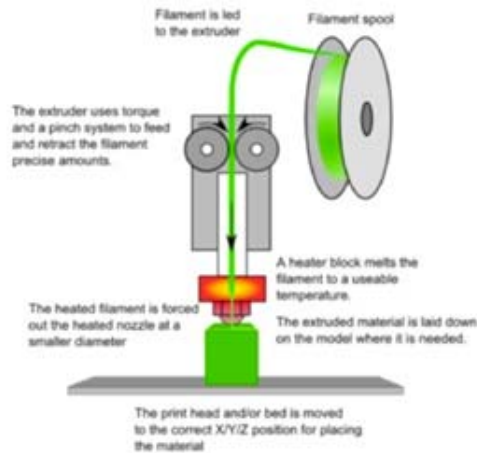
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# Additive Manufacturing

- **3D printing**
  - 3D CAD files are sliced
  - Filament is heated and extruded





# 3D Printing Materials

- **Main 3D printer filaments**
  - PLA
  - ABS
- **Composite materials**
  - Contain metal powders
  - Various fibers

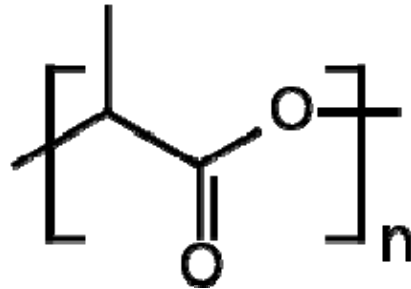




# Polylactic Acid (PLA)

- **Benefits**

- Environmentally friendly
- Does not release toxic fumes/safe for people



- **Disadvantages**

- Does not last as long as other plastics.
- Not as tough as ABS, based on fracture toughness testing





# Applications of Polylactic Acid

- **Films**
  - Food packaging
  - Plastic bags
- **Fibers**
  - Upholstery
  - Disposable garments
- **Biomedical applications**







## Objectives

**Determine the properties of the new PLA composite materials**

- **Microscopy**
- **Tribology**
- **Tensile Strength**
- **Fracture Toughness**
- **Thermogravimetric analysis**
- **Differential Scanning Calorimetry**

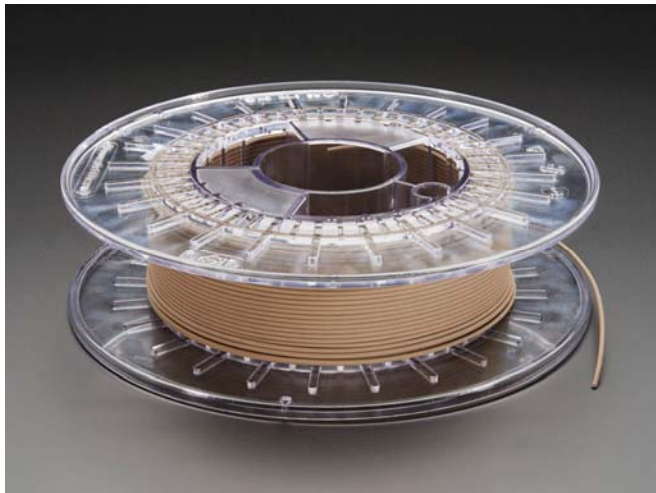
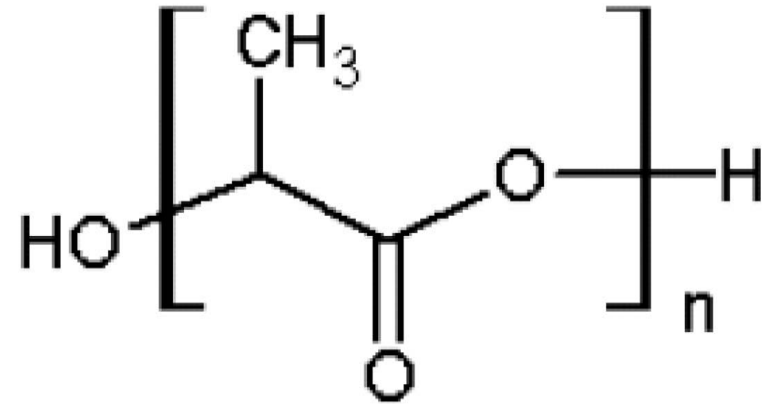
**Compare the properties of the PLA with the PLA composites**

- **Are the PLA composites an improvement on the plain PLA materials?**
- **In what ways are these PLA composite materials an improvement?**



## Materials Used in Present Study

- PLA (Polylactic acid)
- Bronze fill PLA
- Copper fill PLA
- Magnetic Iron PLA
- Stainless Steel PLA



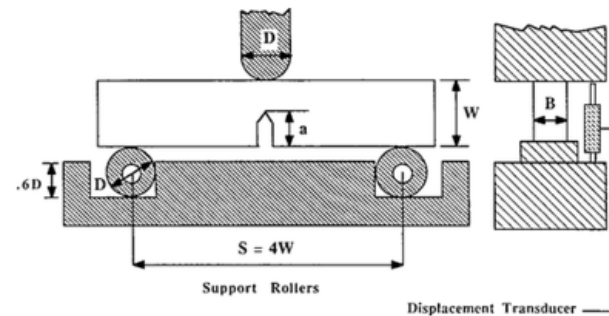


## 3-D Printed Materials

- The test samples were printed at several different layer heights seen below:
  - Tensile bars - 0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm
  - Wear test samples - 0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm
  - Fracture toughness bars - 0.1 mm, 0.3 mm
  - Microscopy samples - 0.1 mm, 0.3 mm



ASTM D638



ASTM D5045

- Three samples per condition

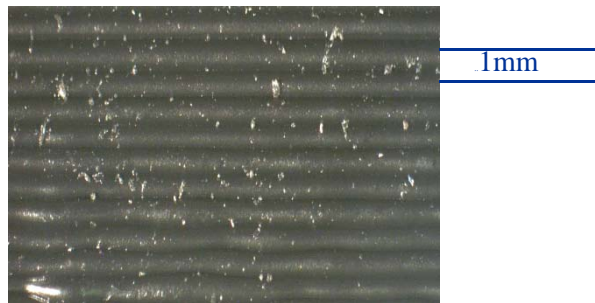




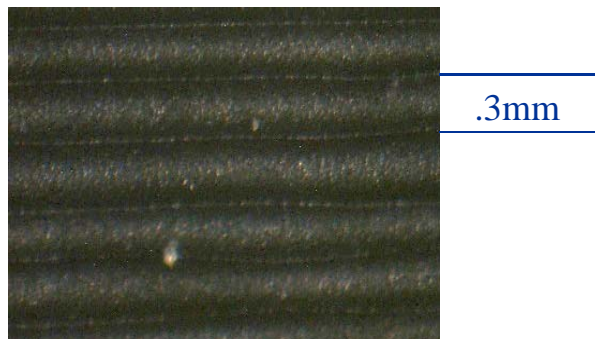
# Macrostructure

- **Print resolution**
  - Prints of different layer heights exhibit different structures. Different mechanical properties?

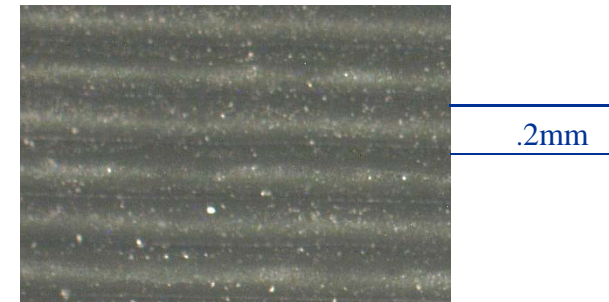
0.1mm



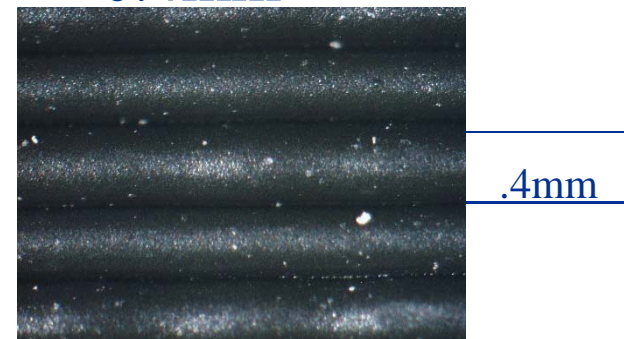
0.3mm



0.2mm



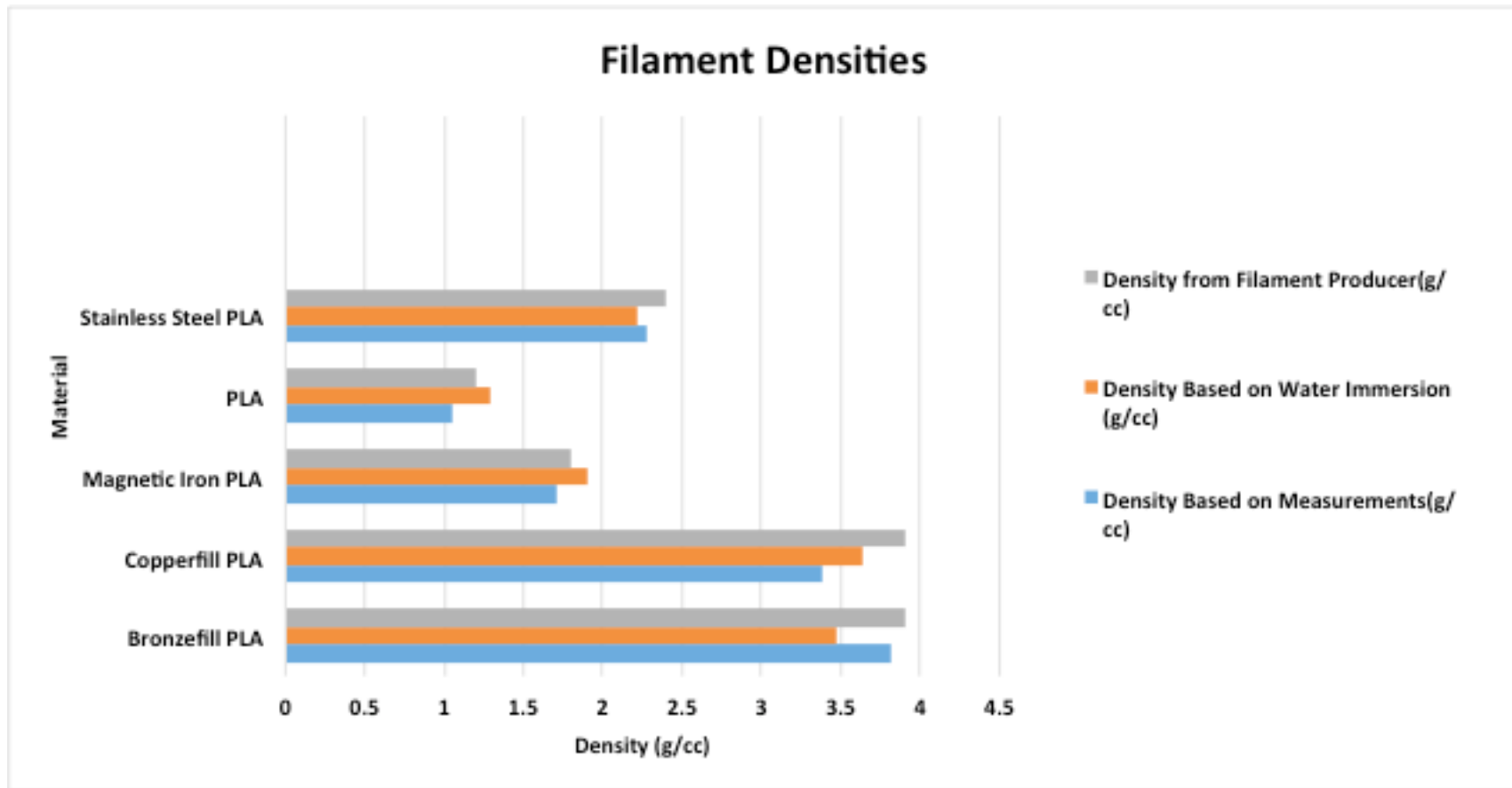
0.4mm





# Density

- **Metal Composite PLA vs. Pure PLA**
  - The metal filled materials had much higher densities than the pure PLA; correlate to metal mass content.



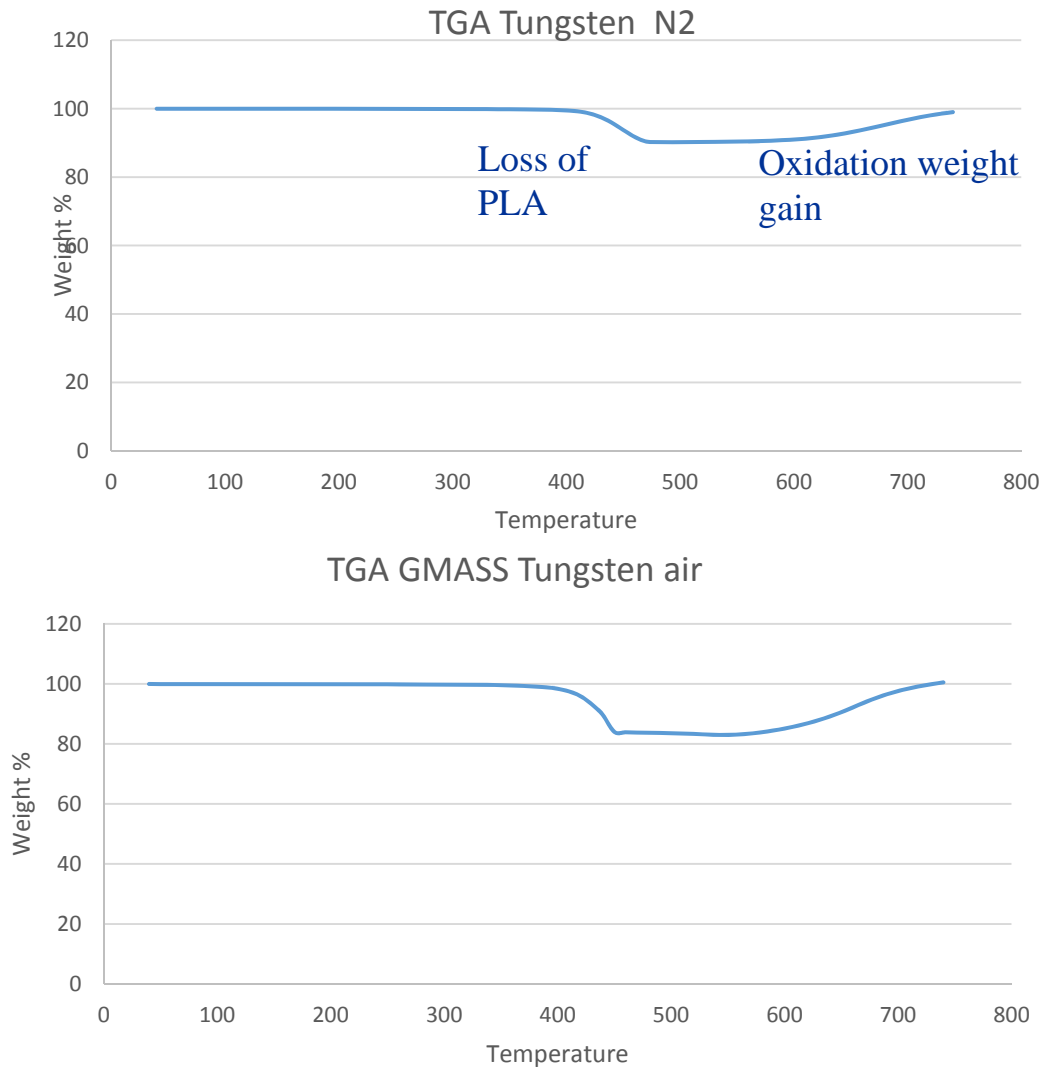


# Thermogravimetric Analysis

<b><u>Filament</u></b>	<b><u>Metal Weight Percentage</u></b>	<b><u>Metal Volume Percentage</u></b>
Bronzefill PLA	80.35%	36.02%
Copperfill PLA	80.57%	36.41%
Stainless Steel PLA	58.87%	18.09%
Magnetic Iron PLA	48.33%	11.05%



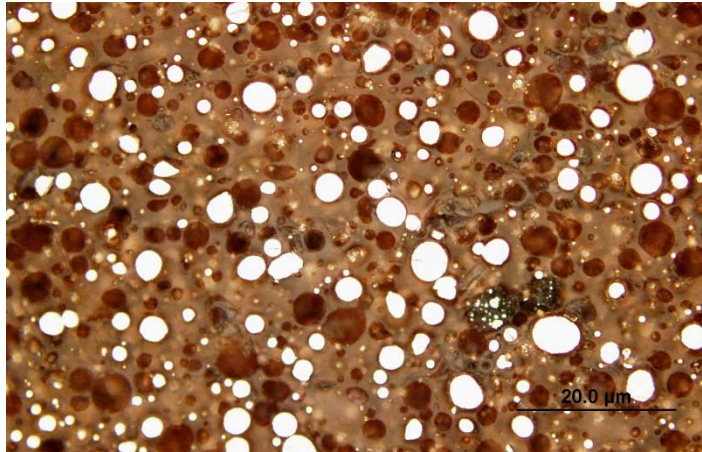
# Thermogravimetric Analysis



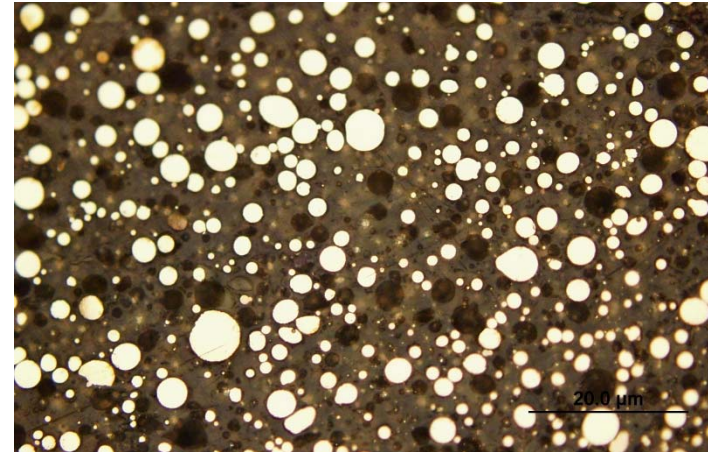


# Microstructure

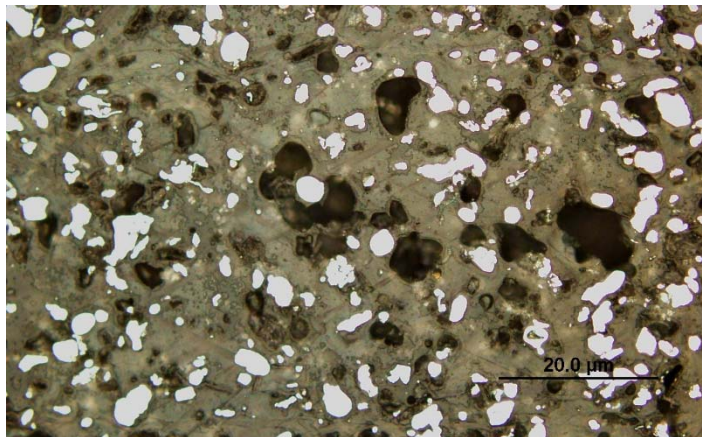
Copper PLA



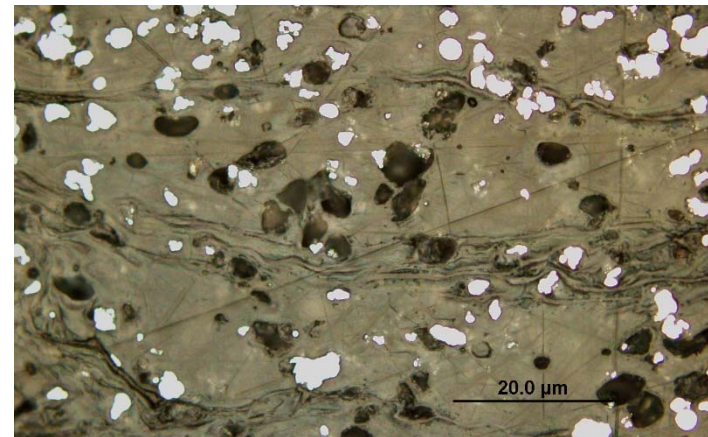
Bronze PLA



Stainless Steel PLA



Magnetic Iron PLA



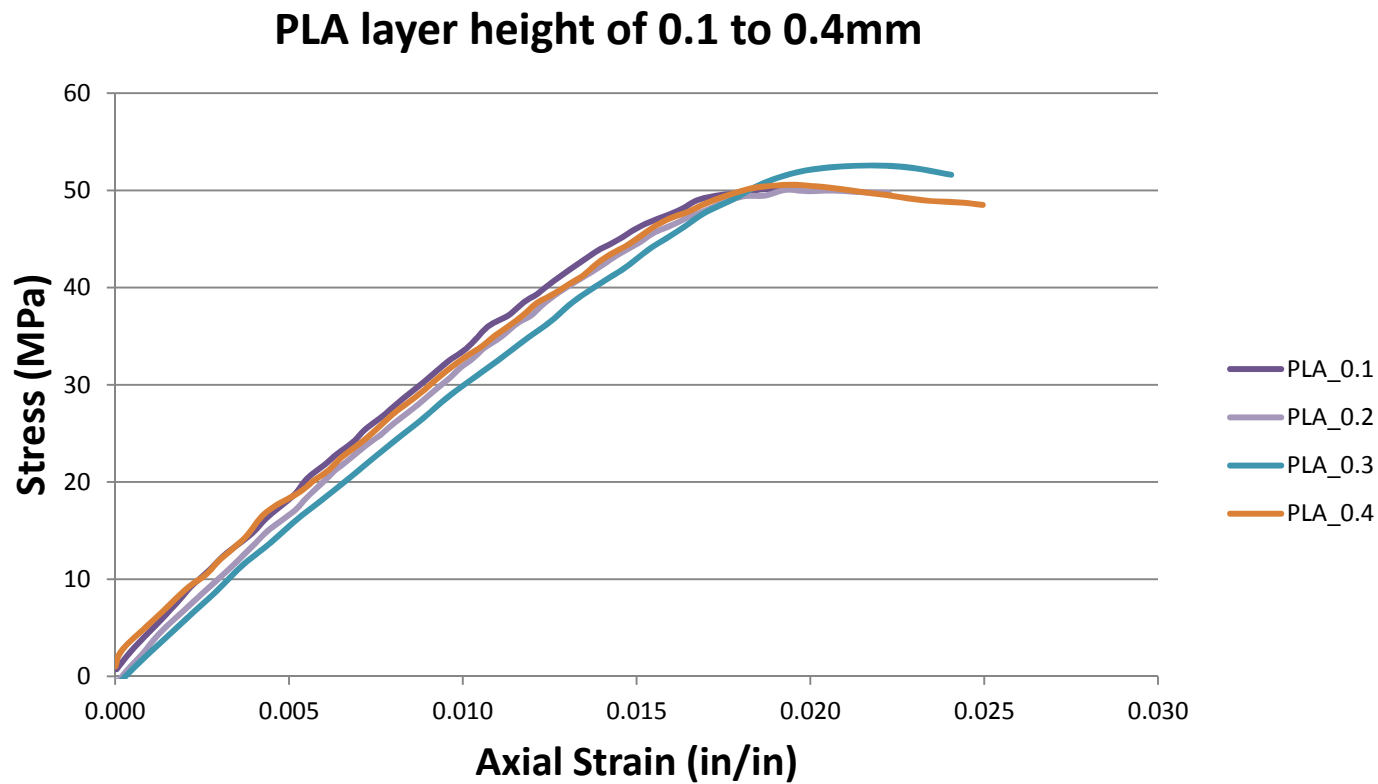
- Spheroidal Cu and bronze particles
- Deformed stainless and iron particles; poor dispersion!





# Tensile Data

- PLA shows no layer height effect:

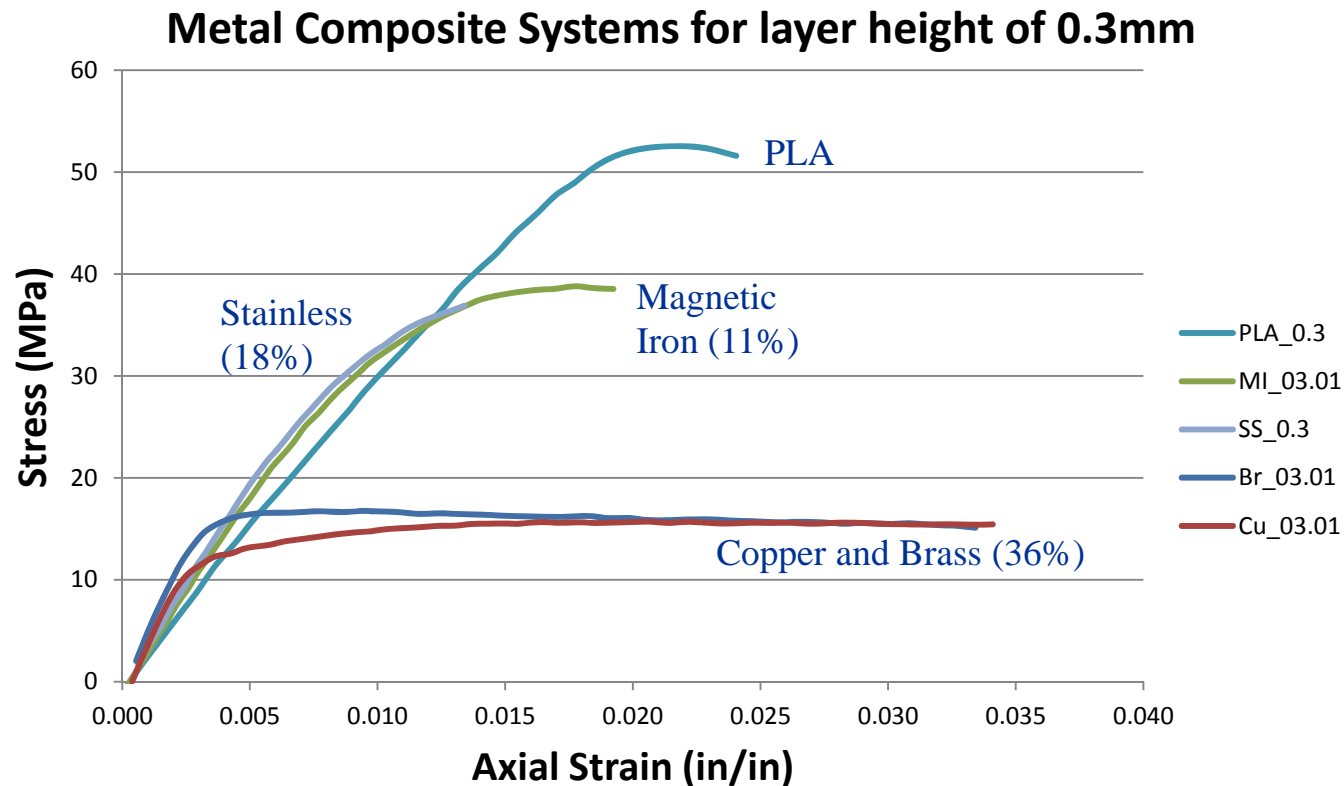






# Tensile Data

- PLA shows the greatest strength:

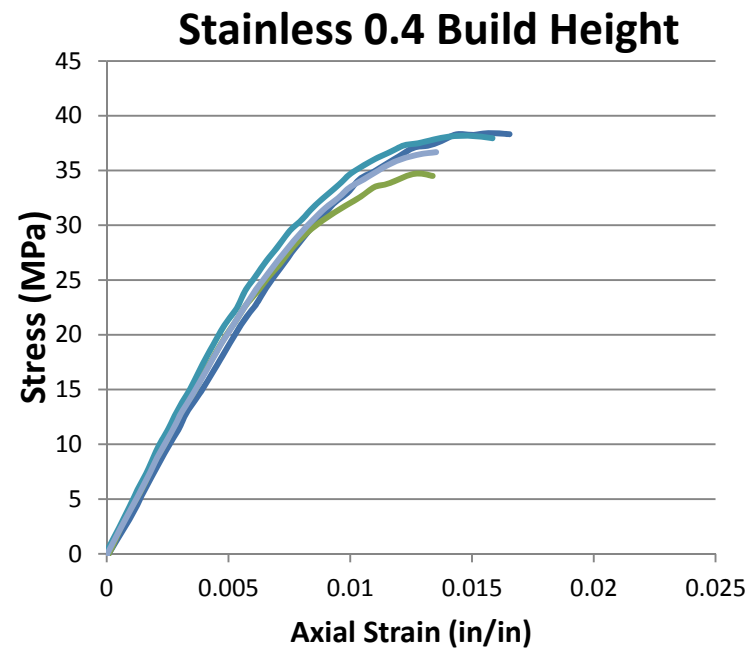
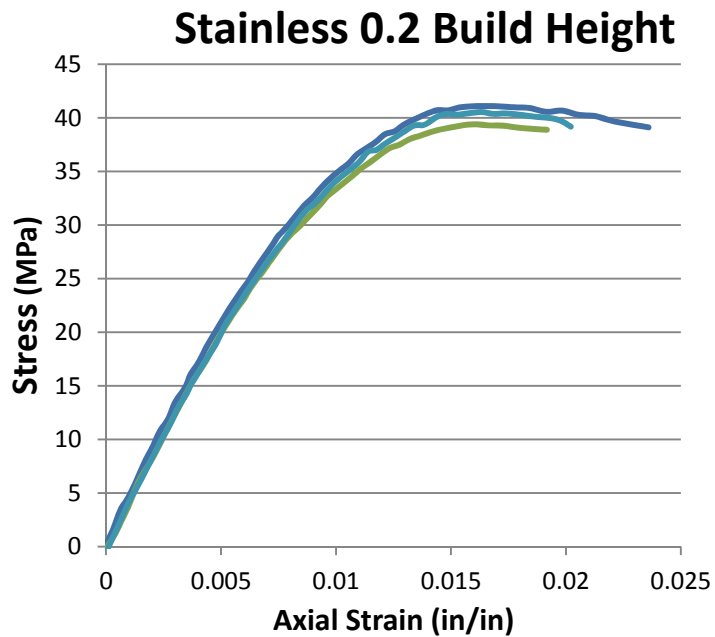


- As the concentration of metal in the filament increases, the strength decreases.



# Tensile Data

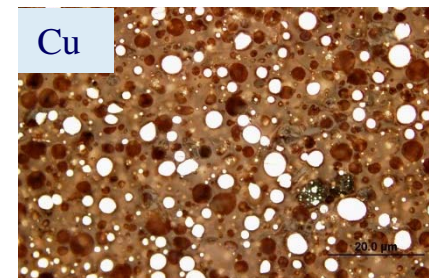
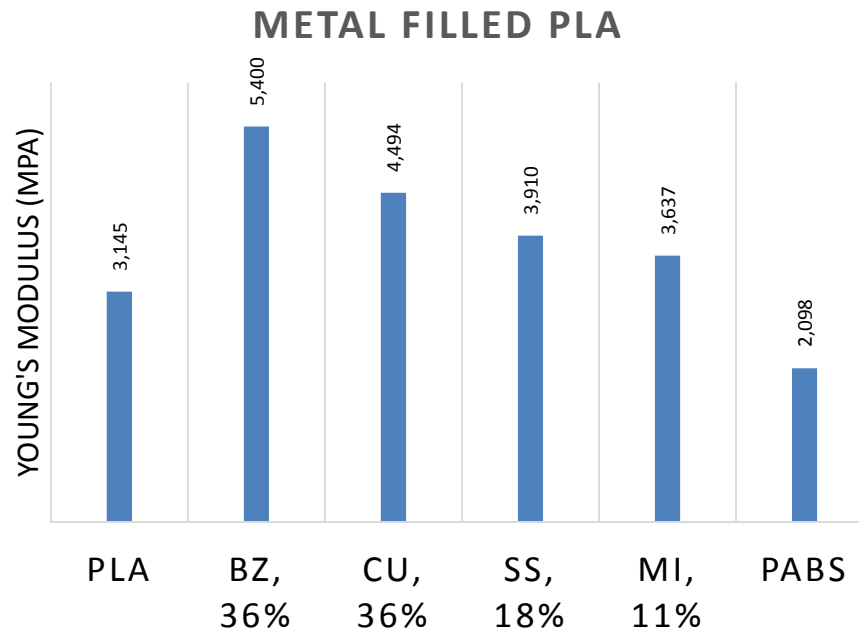
- Metal filled PLA show an effect of layer height:



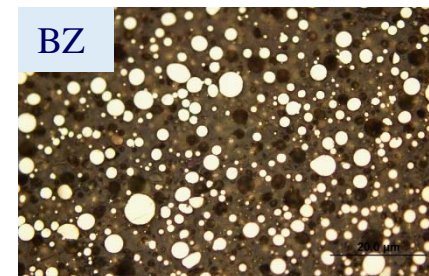
- Lower strength and strain to failure.



# Young's Modulus



$E_{Cu} = 117 \text{ GPa}$   
(higher porosity)

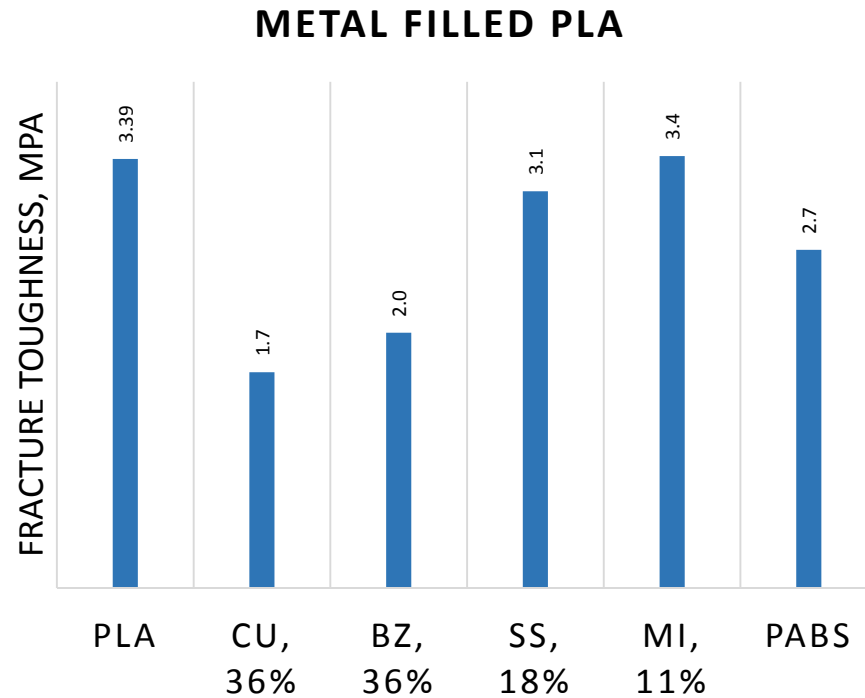


$E_{Bz} = 96-120 \text{ GPa}$

- Young's modulus follows the V% of metal - porosity.
- Still stiffer than premium ABS.
- Poisson's ratio was  $\sim 0.33$ .



# Fracture Toughness



- Generally, the fracture toughness follows the V% of metal.
- PLA has greater toughness than ABS, but metal additions can lower significantly (50% for Cu).



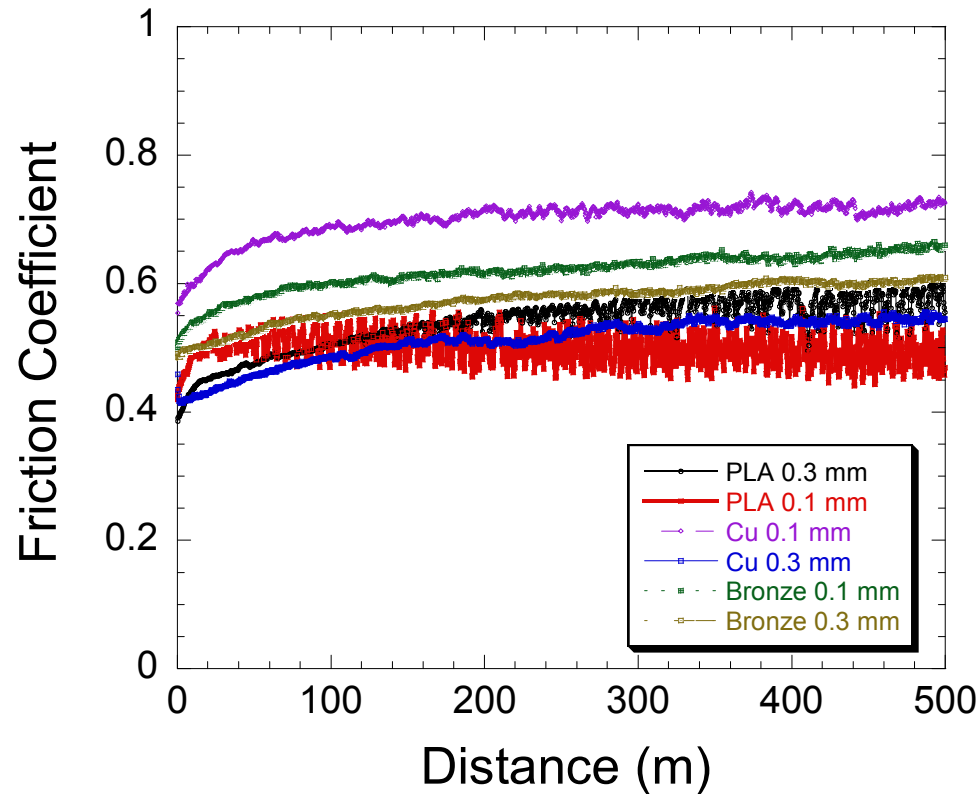
# Fracture Surfaces

- Do we have pictures?



# Tribology

- Friction Coefficient of metal filled PLA:



Related talk to be given on wear etc.

- The metal composite materials generally exhibit a higher coefficient of friction than pure PLA.
- Higher layer height exhibits lower friction.





## Conclusions

- PLA exhibits the greatest strength, with no dependence on layer height.
- Metal filled PLA is stiffer but weaker than unfilled; Good strain to failure is usually exhibited.
- SS filled PLA exhibits lower strain to failure – irregular powder and higher % fill. Bonding? Distribution? Surface finish? Fractography!
- As the metal volume percentage increases, the porosity increases, and lower strength is exhibited.
- Young's Modulus generally increase as the V% of metal increases.
- Fracture toughness decreases as metal content increases.
- Higher coefficient of friction is exhibited by metal filled PLA's.
- Metal powder act as a weak interface thereby lowering strength and toughness.



## Future Work

- **Continuing to process tests, and analyze these metal filled PLA materials.**
- **Characterization of new filaments.**